With R. Beeley Thompson's

Compliments

View of the Bushtenari Oil-Field of Roumania.

Frontispiece.

PETROLEUM MINING

AND

OIL-FIELD DEVELOPMENT

PETROLEUM MINING

AND

OIL-FIELD DEVELOPMENT

A Guide to the Exploration of Petroleum Lands, and a Study of the Engineering Problems connected with the Winning of Petroleum

INCLUDING

STATISTICAL DATA OF IMPORTANT OIL-FIELDS, NOTES ON THE ORIGIN AND DISTRIBUTION OF PETROLEUM, AND A DESCRIPTION OF THE METHODS OF UTILISING OIL AND GAS FUELS

BY

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PREFACE.

THE paucity of practical books on the important subject of Petroleum Mining, which has now assumed such gigantic proportions and proved under careful guidance to be such a lucrative form of investment, is sufficient justification for the preparation of this volume. Whilst a great mass of valuable literature in almost all branches of the petroleum industry has been issued in pamphlet form in many countries and several languages by private individuals and Government officials, the information is not available to the general reader, and there are very few publications where the data are assembled and can be applied in contrasting widely separated oil-fields. The reason is partly due to the world-wide distribution and varied character of oil-fields, which prevents all but a few, who are professionally associated with Petroleum Mining, and who almost exclusively devote their time to that branch of Engineering, from having opportunities of comparing and applying in practice deductions of independent local operators.

Petroleum Mining is a branch of Engineering in which, perhaps, more than in any other, specialisation is essential and practical training necessary, as ordinary mining knowledge does not materially assist the engineer. Petroleum, being a fluid, is subject to laws which apply to no solid mineral. Its distribution and

concentration are dependent upon petrological and stratigraphical features which in no way apply to solid minerals, and its subterranean distribution bears little relationship to the only other fluid which circulates freely in the earth, viz., water. Often intimately mingled with water, and always accompanied by gaseous products, its movements and segregation are determined by factors which affect no other substance, and its migration presents some of the most interesting scientific problems awaiting solution to-day.

The term "mining" has been adopted as descriptive of the operations connected with the exploration and winning of petroleum, for under no other branch of Engineering could the subject be appropriately classified.

None of the engineering colleges has yet taken the initiative of introducing a special course of training for petroleum engineers, although such is, I understand, under consideration. There are few branches of Engineering that offer brighter prospects to an energetic and enterprising engineer, and there is certainly none that presents more varied and interesting problems.

In the search for and winning of petroleum a knowledge of both civil and mechanical branches of Engineering is desirable. The civil side is displayed in the construction and maintenance of roads and light railways, and in the design and erection of buildings, water and oil storages, piers, &c. On the mechanical side is involved the arrangement of power plants of all kinds, the design and manufacture of special tools and instruments for drilling to great depths, often in face of obstacles which invoke the highest skill and ingenuity of the engineer. In the arrangement of installations

for the mechanical extraction of petroleum many opportunities occur for exercising initiative and skill, and in the transport of petroleum other intricate problems arise.

Petroleum producing countries gradually become encircled with pipe lines through which oil is frequently conveyed hundreds of miles with insignificant losses over all kinds of ground. Interesting problems arise in providing for inequalities of temperature, averting air and gas "locks," removing incrustations of solid hydrocarbons which collect on the interior of the mains, and designing pumping machinery which will ensure a constant propulsion of viscous oils without moments of arrested movement.

A knowledge of the principles of geology is desirable, and an acquaintance with chemistry is useful, although the chemistry of petroleum is so little known and understood that years of training can only qualify a student to successfully deal with the scientific treatment of oils which vary in composition in almost every field.

In this volume an attempt has been made to present in practical and concise form an outline of the conditions under which petroleum occurs in nature, and the main problems which have to be solved in the exploration and development of oil-fields.

The subject is introduced by a short historical account and brief mention of the present operated oil-fields, accompanied by statistical data. The subjects of origin of petroleum and its composition, characteristics, distillation, and refining are briefly described to give those interested in oil-field development an idea of those sides of the industry.

The indications of petroleum and the geological

conditions under which it exists in commercial quantities are described in detail with the intention of assisting prospectors in deciding upon the value of territories where manifestations of petroleum are displayed. In the sections dealing with oil-field phenomena and the life and production of oil wells, many interesting figures drawn from various channels have been incorporated, likewise in the pages devoted to the consideration of the life of oil-fields and the quantity of oil secreted in oil strata there will be found a large number of highly instructive figures.

Every endeavour has been made to maintain throughout a practical standard, and numerous examples of phenomena which have either come under the author's personal observation or have been collected from authoritative sources, have been inserted to illustrate features under review and substantiate views expressed.

In the sections of the work devoted to drilling and sources of energy on oil-fields, many useful practical hints may be found, being the result of considerable personal experience in prospecting and developing new territories, where it is necessary to simplify the plant as much as possible as only the most crude local labour is often available.

A special chapter has been devoted to the combustion of liquid fuel, the employment of which is so general in oil-fields and is becoming increasingly popular for railway, naval, and general industrial purposes where cheap supplies are available. The use of natural gas has likewise been separately treated, chiefly on account of the increasing interest shown in its

direction to useful employment in the older oil-fields, where, until recently, economies in fuel consumption were rarely considered. The analyses of natural gases in Chapter IV. and the figures of the yield of gas by bailing wells in the Russian oil-fields, which are the first direct measurements ever taken in those fields, should stimulate energies in the direction of its employment.

In the preparation of this work I have consulted many works of reference, and I have largely availed myself of the valuable and unique publications of the Geological Survey of the United States, from which I have extensively quoted. It is impossible to speak too highly of the care and skill employed in those publications which are invariably enhanced in value by beautifully prepared illustrations and carefully drawn maps.

The statistical matter dealing with the United States oil-fields has been exclusively taken from the exhaustive Annual Reports on the Petroleum Resources of the United States.

Most of the Russian and Roumanian statistical information has been taken from the semi-official papers, *Neftiano Dielo*, and *Moniteur du Petrole Roumain*, and other matter has been abstracted from articles in the *Petroleum Review*. Information regarding the Burma and Assam oil-fields has been taken from Reports issued by the Indian Geological Survey, and particulars of the Dutch East Indian have been collected from many private channels. The Imperial Institute and the Board of Trade willingly extended their assistance when it was sought con-

cerning the Canadian and Indian productions. A great deal of information has been accumulated during my visits to many oil-fields, where operators have always willingly extended to me local information for which I should like to take this opportunity of expressing my sincere thanks.

I am specially indebted to my colleagues Mr Campbell M. Hunter, M.A., A.M.I.C.E., and Mr R. H. Trench, B.A., for critically reading the proofs and for many valuable suggestions to which I readily acquiesced. I also owe a debt of gratitude to my father, Mr Beeby Thompson, F.C.S., F.G.S., for critically reading the geological and chemical portions of the work, and to Mr F. C. Thompson for the care and trouble taken to photograph samples of rocks, bitumens, &c., which have turned out so successfully. I must likewise express my thanks to the United States Geological Survey for forwarding me original photographs by Mr Ralph Arnold, with authority to reproduce, and to my brothers, Mr G. H. Thompson, and to Mr F. W. Thompson, and Mr H. May for preparing many of the drawings which illustrate the work.

Other sources of information are duly acknowledged in the text, but it would be ungrateful to omit a word of praise to the publishers, who have sympathetically greeted all suggestions and never grudged any pains to produce results worthy of their high reputation.

A. BEEBY THOMPSON.

3 LOMBARD STREET,
LONDON, E.C., *December* 1909.

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PETROLEUM MINING

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CHAPTER I.

INTRODUCTORY.

Historical—Geographical Distribution of Petroleum—United States—British Empire—Russia—Dutch East Indies—Austria-Hungary—Roumania—Central America—South America—Germany—Japan—Italy—Africa—Leasing of Oil Lands.

Historical.—Historical references to petroleum and allied substances in literature of great antiquity prove that this widely distributed product of Nature has not only been known for many centuries but has been used in the arts long before the Christian era. Modern antiquarian exploration in Egypt and elsewhere has brought to light many objects on which native bitumen has been used in some form. The Chinese and Japanese have for centuries worked oil deposits in a primitive way, and the Parsees for over a thousand years paid pilgrimages to the Eternal Fires of Baku before its commercial worth was established. Both the Incas of Peru and the Aztecs of Mexico, of which remarkable races so little is known, employed petroleum in their architecture and works of art. The medicinal properties of petroleum were

recognised by the Indians of North America long before the white man set foot there, and the Persians eagerly sought certain Baku oils which were said to be endowed with curative qualities centuries before the Russians occupied the Caucasus. In both Galicia and Roumania there are old works which prove that petroleum was extracted ages before its value was generally appreciated, and the pitch well of Zante has been mentioned in classical literature.

The occurrence of petroleum has often led to the designation of towns, rivers, districts, &c. Thus, in England, there are several Pitchfords which doubtless owe their name to the local occurrence of pitch or oil, and in Canada, Petrolia is the centre of a large oil industry, from which it derives its name. In Spanish-speaking countries, Brea (pitch), La Brea, Breaita, &c., are common appellations for places where oil indications are manifested, and in Persia, Kir (pitch) is frequently prefixed to the names of places indicating the existence of this material. In Burma the word Yenang (earth-oil) prefixed to other words has evidently been applied to localities where there were petroleum manifestations as at Yenangyaung (earth-oil creek) and Yenangyat, where there are now large oil developments. In Barbados, where crude oil has for over a century been exported as Barbados tar, one of the localities is called Mount All, a generally presumed corruption of Mount Oil, while in Russia such names as Neft (oil), Neftiano are met with. Likewise in Germany we find the name of Pechelbronn (*pech*, pitch) given to a place near Hagenau where oil occurs, and on the Red Sea we find Geb-el-Zeit (head of oil), and in Algeria Ain Zeft (oil well), where there are evidences of oil.

In India, China, and America oil was first obtained in association with brine, which was evaporated to produce salt, and often the inflammable gas which commonly accompanied the brine was directed to profitable use. In America some of the early salt manufacturers of the Kanawha district preserved the oil which rose with the salt water and derived a small supplementary income by its sale for lubricating and lighting

purposes. About the year 1820, when means were devised for drilling wells to a depth of 1,000 feet and more, many barrels of oil daily rose with the water, and a regular trade was conducted in this "Seneka" oil.

The first serious public attention was directed to petroleum as a remunerative enterprise when Colonel Drake drilled the first well especially for petroleum in 1859, which led to the development of the great Appalachian oil-fields that have since yielded such an immense volume of the finest crude oil in the world. In 1871 the first well was *drilled* in the Russian oil-fields of Baku, which likewise revolutionised the oil industry in that country and brought about results of which the most sanguine had not even imagined.

Notwithstanding the abundance of petroleum found and its proved value, progress was hindered by the lack of transport to centres of employment. In America and Russia the oil was transported in carts over bad roads at great expense to the nearest railway, and it was not until 1865 that the feasibility of piping the petroleum was demonstrated in America, and ten years later before the first trunk line of any importance was constructed from near Butler to Brilliant Station on the Alleghany River, near Pittsburg. In 1879 the first great seaboard trunk line, six inches in diameter, was commenced from Colegrove, M'Kean County, to Philadelphia, some 235 miles, with a branch five-inch line, 66 miles long, from Millway to Baltimore.

In Russia the same transport difficulties were impeding the growth of the petroleum industry of the Caucasus, and one of the most enterprising Baku producers, following the example of America, constructed a pipe line between the Balakhany oil-fields and the Caspian seaboard at Blacktown. As in America, the carters, who had conducted a lucrative business in transporting oil, fiercely opposed the project, and for a long time it was necessary to guard the line from attacks by the disengaged carriers.

At that time the various oil products were barrelled, and

exported or despatched to their destination in that manner, but the increased trade led distributors to consider cheaper methods, as the barrels often cost far more than the contents. In 1879 Messrs Nobels, one of the largest oil producers in Russia, constructed a steamer provided with tanks for conveying oil in bulk across the Caspian Sea to the Volga where the great markets lay, and the success which rewarded their effort led to the general adoption of this means of transport on the Caspian Sea. About the same time some small ocean-going tankers were constructed, and a few years later tank ships of considerable capacity were built for the conveyance of both refined and crude oil in bulk. In the year 1907 the unexpected developments in the oil industry led to many large tankers being built, the finest vessels having a speed of eleven knots and a capacity of 6,000 to 7,000 tons cargo, besides bunkers for a long voyage.

Between the years 1897 and 1902 the American and Russian outputs kept very close, and for four years, 1898-1901, Russia produced about half the world's supply of petroleum, a result more remarkable when it is considered that the Russian production was obtained from some 2,000 wells spread over an area not exceeding 10 square miles, whereas the other half of the world's output was obtained from tens of thousands of wells spread over many hundreds, if not thousands, of square miles of territory.

A discovery of historical interest in connection with the petroleum industry, which greatly hastened its progress in countries where the percentage of lamp oils was small, was the method of burning heavy residual oils as fuel by pulverisation with a jet of steam or air. Until about the year 1865 there was no commercial demand for the heavy residua of asphaltic oils such as formed over 50 per cent. of Russian oils, and this product, which has for forty years dominated the price of Russian crude oils, was considered a waste product and burnt in open pits around the refineries, the dense smoke from which constituted a public nuisance.

Geographical Distribution of Petroleum.—Although the extraction of petroleum has till recently been confined to a few regions spread over the world, modern exploration and more general knowledge of the indications attending its occurrence is leading to the discovery of numerous oil-fields which will equal in importance, at no distant date, many of the oil-fields operated at present. The main supplies of petroleum in 1909 were derived from the United States—where, owing to the rapid development of new territory, the centre of oil interests moves from year to year—Russia, Roumania, Austria-Hungary (Galicia), East Indian Islands, and Burma, although other important oil-fields are being actively developed in Mexico, Peru, Assam, the West Indies, and Persia, where productive oil-bearing strata have been located over wide stretches of country. Besides these areas where the existence of petroleum in remunerative quantities has been amply demonstrated, there are immense untouched regions in Africa, South America, Canada, and Asia where promising indications occur, although they are often, at the moment, too far removed from transport facilities or labour centres to admit of commercial development. In Russia alone it is estimated that there are 15,000 square miles of oil-bearing territory, although the oil already extracted in that country, amounting to over 160,000,000 tons, has been chiefly obtained from an area of 10 square miles.

The world's production of petroleum in 1908 approximated 40,000,000 tons, but notwithstanding the enormous annual increase in output prices are well maintained, and further demands are made upon the products of petroleum. The industrial supremacy of the United States has not been unaffected by its cheap supplies of that best of all fuels, natural gas, as well as cheap fuel oils, and other countries will not fail to benefit, if oil-fields nearer home are brought to light.

During the next few years great developments may be anticipated in the East Indies, where oil-fields of wonderful richness and extent are said to exist, and it is likely that

Eastern oils will largely supplant the supplies which have until recent years been mainly furnished by America.

Amongst the non-producing and unproven countries where specially encouraging results may be anticipated when development is undertaken are Turkey-in-Asia, Persia, Venezuela, Colombia, Ecuador.

Table I. gives the production of crude petroleum of the chief oil-producing countries of the world. The figures in the case of some countries are approximate only, and there are certain quantities of petroleum produced in some countries and consumed locally which are never recorded.

In every case the extent of development is dictated by local circumstances which directly affect the production. The discovery of new prolific oil-fields for a while demoralises the oil trade of districts which have hitherto supplied the demands of places to which the new product is introduced, and until a demand is created in new channels there is often a surplus production which leads to a temporary fall of prices.

Few products are subject to more severe fluctuations of price than petroleum, although the almost unlimited demand for petroleum products ensures a ready sale when facilities are completed for transport and distribution. Within ten years the price of crude oil in Russia has fluctuated between 7s. to 47s. a ton, and in many of the newer American oil-fields the price has varied from 10s. to 30s. a ton in a few months. Over-production in Galicia (in the sense of insufficient export facilities) in 1908 caused the price of crude to fall to 6s. 6d. a ton, and as recently as 1901 oil was burnt in Borneo as the cheapest method of disposal.

The unavoidable fluctuating value of petroleum is well illustrated by the results attained in the Baku oil-fields of Russia, where, in a month, isolated wells have yielded as much as 400,000 tons of petroleum, equal to the entire annual output of a large oil-field elsewhere, where thousands of wells had been sunk, and hundreds of thousands of pounds spent to secure the same yield.

There are few countries of great extent where there are not some indications of petroleum, and if one includes under oil-fields the oil shales which yield petroleum on distillation, the number is further diminished. Until the oil-fields themselves show signs of exhaustion it is unlikely that the oil shales will be largely treated except in countries where natural supplies are non-existent, and the Governments foster home industries by the imposition of heavy import taxes. In Scotland alone are oil shales distilled at considerable profit in direct competition with imported oils, a result only accomplished by scientific treatment of the shale, strict economy in the working, and the production of valuable bye-products.

Rich oil shales occur in France, Spain, Australia, Brazil, and elsewhere, but only in Australia have they been worked on a large scale outside the United Kingdom.

United States Oil-Fields.—In no country has greater activity been shown in prospecting and developing new oil lands during the last few years than the United States of America, where immense areas of what were almost waste lands have been proved to be oil-bearing territories. So rapid has been the development of the western oil-fields of California, Kansas, Illinois, and Texas, where, however, most of the petroleum is of a lower grade, that the eastern fields of Pennsylvania, Ohio, West Virginia, sink, in comparison, almost into insignificance. Over 300,000 wells have been drilled in the United States oil-fields, and in 1907 the number completed was returned at 19,872, of which 3,594, or 18 per cent., were dry.

Table II. shows the production of the various American oil-fields since 1859, as prepared by the United States Geological Survey. A large proportion of the crude oil is piped to seaboard, where the greatest American refineries are established.

In an official publication of the United States Geological Survey, it was estimated that there were, in 1908, 8,850 square miles of known oil-bearing territory in the country, made up as follows ;—

	Sq. Miles.		Sq. Miles.
Alaska	500	Missouri	30
Alabama	50	New Mexico	80
California	850	New York	300
Colorado	200	Ohio	650
Idaho	10	Oklahoma	400
Illinois	200	Pennsylvania	2,000
Indiana	1,000	Tennessee	80
Kansas	200	Texas	400
Kentucky	400	Utah	40
Louisiana	60	West Virginia	570
Michigan	80	Wyoming	750

Appalachian Field.—The oil-field generally known as the Appalachian field yielded until 1885 practically the whole of the United States supply of oil, and it was the exceptional high grade of the petroleum from this great field which gave American oil such a high reputation in the markets of the world. The Appalachian field extends from the State of New York across Pennsylvania, Eastern Ohio, West Virginia, Kentucky, and Tennessee, and the oils are characterised by their freedom from sulphur, richness in paraffin scale, and high yield of spirit and illuminating oils.

Table III. gives the production of the Appalachian oil-fields since 1859 in United States barrels, in which fields no less than 180,000 wells had been sunk up to the end of 1908.

TABLE III.—PRODUCTION OF PETROLEUM IN THE APPALACHIAN OIL-FIELDS (IN U.S. BARRELS).

Year.	Production.	Year.	Production.	Year.	Production.
1859	2,000	1876	9,120,669	1893	31,365,890
1860	500,000	1877	13,337,363	1894	30,783,424
1861	2,113,609	1878	15,381,641	1895	30,960,639
1862	3,056,690	1879	19,894,288	1896	33,971,902
1863	2,611,309	1880	26,245,571	1897	35,230,271
1864	2,116,109	1881	27,561,376	1898	31,717,425
1865	2,497,700	1882	30,221,261	1899	33,068,356
1866	3,597,700	1883	23,306,776	1900	36,295,433
1867	3,347,300	1884	23,956,438	1901	33,618,171
1868	3,646,117	1885	21,533,785	1902	32,018,787
1869	4,215,000	1886	26,549,827	1903	31,558,248
1870	5,260,745	1887	22,878,241	1904	31,408,567
1871	5,205,234	1888	16,941,397	1905	29,366,960
1872	6,293,194	1889	22,355,225	1906	27,741,472
1873	9,893,786	1890	30,053,307	1907	25,342,137
1874	10,926,945	1891	35,848,777	1908	24,945,517
1875	8,787,514	1892	33,432,377		

Table IV. gives the production of petroleum from the various States covered by the Appalachian oil-fields since 1900.

TABLE IV.—PRODUCTION OF PETROLEUM FROM THE VARIOUS STATES COVERED BY THE APPALACHIAN OIL-FIELDS (IN U.S. BARRELS).

Year.	Pennsylvania and New York.	West Virginia.	South-Eastern Ohio.	Kentucky and Tennessee.	Total.
1900	14,559,127	16,195,675	5,478,372	62,259	36,295,433
1901	13,831,996	14,177,126	5,471,790	137,259	33,618,171
1902	13,183,610	13,513,345	5,136,501	185,331	32,018,787
1903	12,518,134	12,899,395	5,586,433	554,286	31,558,248
1904	12,239,026	12,644,686	5,526,571	998,284	31,408,567
1905	11,554,777	11,578,110	5,016,736	1,217,337	29,366,960
1906	11,500,410	10,120,935	4,906,579	1,213,548	27,741,472
1907	11,211,606	9,095,296	4,214,391	820,844	25,342,137
1908	10,584,953	9,523,176	4,110,121	727,767	24,945,517

Lima-Indiana Fields.—These oil-fields are located in the north-west of Ohio and in the State of Indiana, and the oil is obtained from the Trenton limestone. The oil is characterised by its high percentage of sulphur, to remove which from the distillates special measures have to be adopted.

Table V. gives the production from the Lima-Indiana field since 1902.

TABLE V.—PRODUCTION OF PETROLEUM FROM LIMA-INDIANA OIL-FIELD.

Year.	Production in Barrels.
1902	23,358,826
1903	24,080,264
1904	24,689,184
1905	22,294,171
1906	17,554,661
1907	13,121,094
1908	10,032,305

Illinois Fields.—The oil-fields of this State are spread over no less than six counties where oil is found in both limestones and sandstones. In 1907 about 5,000 wells were drilled in the State, of which some 690 were dry, and the production

increased about five-fold. Formerly the small production from this field was grouped with that of the Lima-Indiana oil-fields.

Table VI. shows the production since 1905.

TABLE VI.—PRODUCTION OF PETROLEUM FROM ILLINOIS OIL-FIELDS SINCE 1905 (IN U.S. BARRELS).

Year.	Quantity.
1905	181,084
1906	4,397,050
1907	24,281,973
1908	33,685,106

The Mid-Continental Fields. — The Mid-Continental field, which is understood to include the south-eastern portion of Kansas, Northern Texas, and the oil districts of Oklahoma, was brought into public prominence by the development of the famous Glenn Pool in Oklahoma, where the production rose from less than 400,000 barrels in January 1907 to nearly 2,450,000 barrels in October of the same year, although a considerable fall was thenceforth recorded. Table VII. gives the production of this field.

TABLE VII.—PRODUCTION OF CRUDE PETROLEUM IN THE MID-CONTINENTAL OIL-FIELD, 1889-1907, BY STATES (IN U.S. BARRELS).

Year.	Kansas.	Oklahoma.	Northern Texas.*	Total.
1889 to 1895	110,530	287	...	110,817
1896	113,571	170	1,400	115,141
1897	81,098	625	65,925	147,648
1898	71,980	...	544,620	616,600
1899	69,700	...	668,483	738,183
1900	74,714	6,472	†836,039	917,225
1901	179,151	10,000	†800,545	989,696
1902	331,749	37,100	617,871	986,720
1903	932,214	138,911	501,960	1,573,085
1904	4,250,779	1,336,748	569,102	6,186,629
1905	‡12,013,495	§	520,282	12,533,777
1906	‡21,718,648	§	1,117,905	22,836,553
1907	45,933,649	§	912,618	48,846,267
1908	47,600,546	§	723,264	48,323,810

* Includes counties of Navarro, Jack, and M'Lennan.
† Includes a small production in Southern Texas.
‡ Includes the production of Oklahoma.
§ Included in Kansas production,

The Gulf Field.—The Gulf field, which includes the oil-fields of Louisiana and coastal Texas, has been rendered noteworthy by the great Spindle Top Field which aroused world-wide attention in 1902. Table VIII. gives the output from this field.

TABLE VIII.—PRODUCTION OF PETROLEUM IN THE GULF FIELD SINCE 1889 (IN U.S. BARRELS).

Year.	Coastal Texas.	Louisiana.	Total.
1889 to 1900	2,441	...	2,441
1901	3,593,113	...	3,593,113
1902	17,465,787	548,617	18,014,404
1903	17,453,612	917,771	18,371,383
1904	21,672,311	2,958,958	24,631,269
1905	27,615,907	8,910,416	36,526,323
1906	11,449,992	9,077,528	20,527,520
1907	11,410,078	5,000,221	16,410,299
1908	10,483,200	6,835,130	17,318,330

Table IX. shows the production from the various oil-fields of Texas.

TABLE IX.—PRODUCTION OF PETROLEUM IN TEXAS SINCE 1896 (IN U.S. BARRELS).

Year.	Corsicana.	Powell.	Spindle Top.	Sour Lake.	Saratoga.	Batson.
1896	1,450	...	...	...	...	...
1897	65,975	...	...	...	...	...
1898	544,620	...	...	...	...	...
1899	668,483	...	...	...	...	...
1900	829,560	6,479	...	...	...	...
1901	763,424	37,121	3,593,113	...	...	...
1902	571,059	46,812	17,420,949	44,838		...
1903	401,817	100,143	8,600,905	8,848,159		4,518
1904	374,318	129,329	3,433,842	6,442,357	739,239	10,904,737
1905	311,554	132,866	1,652,780	3,362,163	3,125,028	3,774,841
1906	332,622	673,221	1,077,492	2,156,010	2,182,057	2,289,507
1907	226,311	596,897	1,699,943	2,353,940	2,130,928	2,164,453
1908	211,117	421,659	1,747,537	1,595,060	1,634,786	1,593,570

TABLE IX.—PRODUCTION OF PETROLEUM IN TEXAS SINCE 1896 (IN U.S. BARRELS)—*continued.*

Year.	Dayton.	Matagorda.	Henrietta.	Humble.	Other.	Total.
1896	...	...	...	...	...	1,450
1897	...	...	...	...	...	65,975
1898	...	...	...	...	1,450	546,070
1899	...	...	...	...	530	669,013
1900	...	...	...	...	...	836,039
1901	...	...	...	...	...	4,393,658
1902	...	...	...	...	...	18,083,658
1903	...	...	...	...	30	17,955,572
1904	...	151,936	65,455	...	200	22,241,413
1905	60,294	46,471	75,592	15,594,310	300	28,136,189
1906	92,850	*80,591	111,072	3,571,445	1,030	12,567,897
1907	108,038	*13,267	83,260	2,929,640	16,019	12,322,696
1908	39,901	62,640	85,963	3,778,521	35,710	11,206,464

* Includes the production of Hoskins Mound.

Louisiana Fields.—The Louisiana oil development operations have been confined to three or four districts which gave productions as below.

TABLE X.—PRODUCTION OF PETROLEUM IN LOUISIANA SINCE 1902 BY DISTRICTS (IN U.S. BARRELS).

Year.	Jennings.	Welsh.	Anse-la-Butte.	Total.
1902	548,617	...	...	548,617
1903	892,609	25,162	...	917,771
1904	2,923,066	35,892	...	2,958,958
1905	8,891,416	10,000	9,000	8,910,416
1906	9,025,174	23,996	*28,358	9,077,528
1907	4,895,905	47,316	*57,000	5,000,221
1908	6,118,875	31,555	*684,600	6,835,130

* Includes the production of Caddo district.

Californian Fields. — The Californian oil-fields have attracted more attention than any others in America during the last few years, as so many important districts have been opened up that the production has trebled in five years. Only a few districts yield a light oil from which fair illuminants can be obtained, the bulk being dense and heavily charged with sulphur, and suitable chiefly for fuel purposes.

PLATE I.

FIG. 1.—VIEW OF LOS ANGELES OIL-FIELD, CALIFORNIA.

A typical illustration of an oil-field located on a sharply inflected anticline where the width over which wells can be profitably drilled is confined to strict limits.

[To face page 12.

PLATE II.

FIG. 2.—VIEW OF LOS ANGELES OIL-FIELD, CALIFORNIA.

(Continuation from Fig. 1.)

[*To face page* 12.

TABLE XI.—PRODUCTION OF PETROLEUM IN CALIFORNIA SINCE 1897 (IN U.S. BARRELS).

Year.	Fresno.	Kern.	Los Angeles.	Orange.	Santa Barbara.	Ventura.	Santa Clara.	San Mateo.	Total.
1897	70,140	...	1,318,853	12,000	130,136	368,282	4,000	...	1,903,411
1898	154,000	10,000	1,470,990	60,000	132,217	427,000	3,000	...	2,257,207
1899	439,372	15,000	1,373,576	108,077	208,370	496,200	1,500	...	2,642,095
1900	532,000	892,500	1,730,263	372,200	153,750	418,000	771	...	*4,324,484
1901	780,650	4,493,455	2,188,633	724,565	135,900	463,127	...	...	8,786,330
1902	572,498	9,705,703	1,938,114	1,038,549	242,840	484,764	...	1,800	13,984,268
1903	2,138,058	18,077,900	2,087,627	1,413,782	306,066	348,295	5,607	5,137	24,382,472
1904	5,114,958	19,608,045	2,102,892	1,473,335	789,006	517,770	41,928	1,500	29,649,434
1905	10,967,015	14,487,967	3,469,433	1,429,688	2,684,837	337,970	50,563		33,427,473
1906	7,991,039	14,520,864	3,449,119	2,032,637	4,774,361	299,124	*31,464		33,098,598
1907	8,871,723	15,652,156	3,477,235	2,604,982	8,708,077	357,094	*77,108		39,748,375
1908	10,386,168	18,132,893	4,692,495	3,358,714	7,816,682	379,044	*88,741		44,854,737

* Includes oil produced in San Luis Obispo County.

Utah, Wyoming, and Colorado Fields.—Utah and Wyoming have yielded small supplies of petroleum, that extracted from some districts of the latter State having a high value as a natural lubricating oil. Colorado has also produced supplies of petroleum, as shown in Table XII.

TABLE XII.—PRODUCTION OF PETROLEUM IN COLORADO SINCE 1887 (IN U.S. BARRELS).

Year.	Quantity.	Year.	Quantity.	Year.	Quantity.
1887	76,295	1894	515,746	1901	460,520
1888	297,612	1895	438,232	1902	396,901
1889	316,476	1896	361,450	1903	483,925
1890	368,842	1897	384,934	1904	501,763
1891	665,482	1898	444,383	1905	376,238
1892	824,000	1899	390,278	1906	327,582
1893	594,390	1900	317,385	1907	331,851
				1908	379,653

Oil-Fields of the British Empire.—The exceptional success which has rewarded the experiments of the Admiralty in the use of liquid fuel for naval purposes has led the British Government to encourage in every possible way the exploration of oil-fields in British territory, especially as, until recently, Great Britain was almost entirely dependent on foreign supplies of oil for all purposes. That there are vast sources of petroleum in British colonial possessions and dependencies inferior to none in the world has been proved by the great developments in Burma, but there are other fields no less important awaiting exploration and development, as will be seen from the following brief description of a few operated and prospective new fields.

East Indies—*Burma.*—One of the most important oil-fields, not only of the British Empire, but of the world, is being developed with considerable activity in Upper Burma, where the conditions indicate the occurrence of a rich oil-field of great area. The oil-bearing strata of Tertiary age are thrust

into a series of anticlinal folds in the vicinity of the Irawadi River, some 300 to 350 miles north of Rangoon, where superior grade, paraffin-bearing oils are obtained in considerable quantities at moderate depths. The two chief fields already worked are the Yenangyaung and Yenangyat, the former occurring on the east of the Irawadi in the Myingyan district, the latter being located 55 miles farther north on the Singu hills to the east of the river and the Tangyi hills to the west of the Irawadi in the Pakoku district. Geological surveys undertaken by the Indian Geological Survey have proved the occurrence of anticlinal folds parallel to the above-named ridges in the Pagan and Gwego hills, where the oil-bearing series are brought near to the surface, and indications justify the belief that petroleum exists in remunerative quantities.

The Burma crude oil has a specific gravity of from .820 to .840, and often contains from 5 to 10 per cent. of paraffin wax, which is extracted for the manufacture of candles, but some Singu oil has a specific gravity below .820, and contains a large percentage of spirit. The wells vary in depth from 700 to 1,500 feet, and often yield by flowing from 100 to 200 tons (750 to 1,500 barrels) of oil daily when new, although they have to be pumped later.

Until 1908 the Burma Oil Company, who, as pioneers, secured a large number of well-selected areas, practically monopolised the Burma oil-fields, but the success of that corporation has induced general interest, and considerable activity is likely to be developed during the next few years, when large new plots will most certainly be opened up by Indian merchants and others who have acquired grants of oil-bearing lands.

Table XIII. gives the productions of the Burma oil-fields in U.S. barrels.

The Yenangyat and Yenangyaung oil-fields have been connected by pipe lines, and the Burma Oil Company has laid a pipe line to Rangoon to save the barge conveyance down the Irawadi River.

TABLE XIII.—PRODUCTION OF BURMA OIL-FIELDS (IN U.S. BARRELS).

Year.	Burma.	Year.	Burma.	Year.	Burma.
1888 -	79,600	1895 -	370,900	1902 -	1,565,000
1889 -	85,500	1896 -	423,500	1903 -	2,439,000
1890 -	132,500	1897 -	541,000	1904 -	3,304,000
1891 -	189,000	1898 -	526,500	1905 -	4,065,000
1892 -	242,100	1899 -	923,500	1906 -	3,929,000
1893 -	293,800	1900 -	1,053,000	1907 -	4,249,000
1894 -	312,100	1901 -	1,411,000	1908 -	4,960,000

Assam.—The frequency of oil indications in Assam had been the subject of comment, and even investigation, for nearly forty years before any active measures were taken to prospect, when the Assam Oil Company was formed. The Assam oil is found in strata of Tertiary age on anticlinal folds in the north-east of the province, and usually the oil occurs in association with coal, which is also worked to some extent. The Assam Oil Company have their works at Digboi, some 60 miles inland from Debrugarb on the Brahmapootra River, where wells sunk in disturbed strata yield for a time good supplies of paraffin-bearing oils. Petrol, illuminating oils, and paraffin are prepared in a refinery and distributed along the Brahmapootra River.

Table XIV. gives the production of Assam.

TABLE XIV.—PRODUCTION OF ASSAM OIL-FIELDS (IN U.S. BARRELS).

Year.	Assam.	Year.	Assam.	Year.	Assam.
1890 -	400	1896 -	6,840	1902 -	50,200
1891 -	...	1897 -	6,350	1903 -	72,350
1892 -	...	1898 -	15,680	1904 -	73,980
1893 -	2,335	1899 -	17,810	1905 -	78,060
1894 -	4,765	1900 -	21,500	1906 -	82,800
1895 -	1,041	1901 -	18,050	1907 -	90,200
				1908 -	93,000

The frequent indications of petroleum over a wide area show that the oil occurrence is not confined to narrow limits, and more methodical prospecting appears warranted.

Punjab.—Some small quantities of petroleum are obtained in the Rawalpindi district of the Punjab in beds of Tertiary age.

Baluchistan.—Many natural oil springs have been known in Baluchistan, some of the most important occurring in the vicinity of Moghal Kot, where an anticline fold with open beds occurs.

Arakan Coast.—A small quantity of petroleum has been extracted from the islands off the Burma coast, where indications of petroleum are known to occur on a vast scale, described elsewhere.

Canada.—Although indications of petroleum have been reported from many parts of Canada, no fields have been operated to any important extent except those of Ontario, where the oil appears to be confined to sandstones and limestones of Palæozoic age. The producing fields of Ontario are chiefly located in Lambton County, and the township of Petrolia is the centre of the petroleum interests. Many of the wells in the Petrolia district do not exceed a depth of 500 feet, and their cost is often below £100, as the limestones in which the oil is found are very easy to drill. In some other districts, as Tilbury, the wells are deeper, and they cost a much larger sum to complete.

The Ontario oil is usually of the paraffin class, and is rich in illuminating products, but it contains an excessive amount of sulphur. which imparts to it an offensive odour The wells do not often yield more than twenty-five barrels monthly after sometimes a primary spurt, often only five barrels a month after many years.

Table XV. gives the Canadian production since 1881.

TABLE XV.—PRODUCTION OF CANADIAN OIL-FIELDS (IN U.S. BARRELS).

Year.		Barrels.	Year.		Barrels.	Year.		Barrels.
1881	-	368,987	1890	-	795,030	1899	-	808'570
1882	-	389,573	1891	-	755,298	1900	-	710,498
1883	-	472,866	1892	-	779,753	1901	-	622,392
1884	-	571,000	1893	-	798,406	1902	-	530,624
1885	-	587,563	1894	-	829,104	1903	-	396,200
1886	-	584,061	1895	-	726,138	1904	-	492,492
1887	-	713,728	1896	-	726,822	1905	-	634,095
1888	-	695,203	1897	-	709,857	1906	-	569,753
1889	-	704,690	1898	-	758,391	1907	-	778,872
						1908	-	527,987

Several important attempts have been made to develop an oil-field in New Brunswick, where indications of petroleum are prevalent, but although wells have been sunk to a depth of 2,000 feet, and high-grade oil has been struck, the quantities have been so small that the lands could not be profitably developed. In the Provinces of Alberta, British Columbia, and Athabasca, there are numerous exudations of gas and outcrops of tar sands which justify the conclusion that oil in quantity does exist in these provinces, and it is certain that these regions will attract greater attention as the country develops and access is simplified.

West Indies—*Trinidad.*—In Trinidad are some of the most promising oil-fields of the British Empire. The famous Pitch Lake of Trinidad, fully described on p. 106, has been worked for many years, although the relationship of its contents with petroleum does not seem to have been conjectured until quite recently. Geological investigations undertaken by the Trinidad Government led to the mapping of a series of anticlines resembling in structure those of many productive oil-fields, and certain petroliferous horizons were located which would certainly prove productive if penetrated in suitable positions. The author spent many months in the years 1905 and 1906 in personally investigating

the Trinidad oil deposits, and formed a high estimate of their value in certain districts, a view which has been confirmed by the highly encouraging results obtained in many bore-holes sunk in carefully chosen positions in 1908-9. The oil is found in anticlinal folds of Tertiary strata traversing the southern part of the island in an approximately eastern and western direction, and it is practically assured that many square miles of the oil-yielding land will be proved during the next few years. Oil has been struck in quantities in wells near Guayaguayare on the south-eastern coast, also on the outskirts of the Pitch Lake, and at Guapo on the south-western coast, and in smaller quantities it has been struck in wells at Aripero near San Fernando, and near Williamsville in the Mount Serrat district. The oil has almost exclusively an asphaltic base and often contains sulphur, but seepages of paraffin oils have been met with showing that this latter type may be found. No Trinidad petroleum has yet been marketed.

Barbados.—In the Scotland district of Barbados there are disturbed Tertiary strata which show unmistakable indications of petroleum, and some limited exploration work was undertaken by the West Indian Petroleum Company, which had only overcome the drilling difficulties when the financial resources were exhausted. The island is covered by coral, except in the central part which reaches an elevation of over 1,000 feet, but nowhere is it anticipated that the thickness of coral precludes the possibility of reaching the petroliferous sedimentary rocks beneath, although nothing but drilling can divulge the structural features of the hidden beds.

In several localities petroleum oozes from the ground, whilst in the search for "manjak," a natural bitumen found in the island, heavy petroleum is often encountered. Barbados tar, a natural heavy petroleum found in the Scotland district, has been exported for over a century, although its connection with petroleum was not till recently realised. Amidst a series of shales and limestones, there are many oil-bearing

sandstones which yield for a time a high-grade petroleum with a paraffin base when penetrated at a depth. Some wells sunk to a depth of 500 to 1,500 feet have flowed intermittently for a while and yielded a remunerative supply of oil, but the output has rapidly fallen to a nominal amount only. The author personally inspected this field in 1906, and he concluded that although the strata appear to be considerably disturbed in the Scotland district, where the drilling operations have been so far confined, the results achieved amply justified further prospecting. There is no doubt that if the difficulties of drilling in the disturbed and inclined strata can be overcome, Barbados petroleum can be worked profitably on a commercial scale.

West African Colonies.—On both the Gold Coast and Nigeria some attention has been devoted to petroleum exploration as a consequence of the occasional occurrence of bituminous sands, but so far no signal success has rewarded the efforts of operating companies although traces of oil have been struck. The climatic conditions are not of the best, and little direct evidence of the conditions most suitable for the preservation and accumulation of petroleum in large supplies can be obtained, as the whole country is clothed in dense jungle.

In 1908 the author led an expedition on the Ivory Coast in the neighbourhood of the Gold Coast frontiers, and a line of bituminous strata was traced along the borders of the Assini Lagoon leading towards the Gold Coast, but some miles inland a ridge of granites occurred, and beyond that were auriferous quartzes and volcanic rocks, thus diminishing the prospect of finding petroleum far from the coast. Prospecting operations are being energetically prosecuted by several companies on the Gold Coast, Nigeria, and Ivory Coast, so that the worth of the deposits will be definitely established within a few years.

Russia—*Baku Oil-Fields.*—The Baku oil-fields of Russia have attained world-wide fame as a consequence of the prodigious yields of isolated wells which have for weeks produced daily as much oil as an ordinary field with hundreds of wells would produce in a year. The two most important oil-fields lie within a few miles of Baku on the Caspian Sea, to which port all the crude oil is conveyed by pipe line or barge for refining. The Balakhany-Saboontchy-Romany district with its more recent extension towards Surakhany occupies an area of some 4 square miles, 10 miles north-west of Baku, and the Bibi-Eibat field, with an area of about 1.6 square miles, lies several miles south of the town of Baku on the Caspian shores. Nineteen hundred and forty wells, distributed over a total area not exceeding 6 square miles, yielded in the year 1901 more than half the world's supply of petroleum. The strata are of Tertiary geological age, and the wells are difficult to drill on account of the disturbed and loose nature of the strata, which makes it impossible to proceed far without lining. The wells often exceed 2,000 feet in depth, and occupy twelve to twenty months to drill, and some cost as much as £10,000. The steady decline in the production of the wells, although annually carried deeper and deeper, testifies to the gradual exhaustion of the great Baku fields in the areas already exploited, and if the production of those fields is to be maintained, new lands must be leased to operators by the Government.*

Considerably over 1,000 miles of drilling have been performed in the Baku oil-fields, and more than 700,000 tons of iron have been sunk into the earth as casing, and remains irrecoverable. The average cost of Baku oil wells has not been much below £5,000.

Table XVI. gives the production of the Russian oil-fields, and Table XVII. the particulars of the various districts of the Baku oil-fields.

* For full particulars and statistics of Russian oil-fields see "Oil-Fields of Russia," by A. Beeby Thompson, 1908, 2nd edition. Crosby Lockwood.

TABLE XVI.—Production of Baku Oil-Fields—Apsheron Peninsula (in Poods and Tons).

Year.	Poods.	Tons.
1892	286,513,840	4,606,332
1893	324,773,197	5,221,434
1894	297,551,074	4,783,779
1895	337,426,620	5,424,865
1896	386,264,782	6,210,045
1897	422,460,751	6,791,989
1898	485,715,608	7,808,932
1899	524,034,019	8,424,984
1900	600,357,295	9,652,117
1901	670,808,145	10,784,697
1902	635,040,433	10,209,653
1903	596,346,508	9,587,564
1904	614,724,494	9,883,030
1905	409,583,424	6,584,942
1906	448,047,000	7,203,328
1907	476,217,000	7,656,221
1908	466,786,000	7,504,598

TABLE XVII.—Production of Baku Oil-Fields.

Balakhany.

Year.	Number of Productive Wells.	Total Production in Poods.	Average Production per Well.
1892	169	57,472,460	340,073
1893	175	57,833,430	330,400
1894	193	59,035,523	305,882
1895	230	67,558,297	292,579
1896	290	85,647,175	295,335
1897	387	96,315,225	248,876
1898	485	108,836,439	224,611
1899	610	114,854,151	188,285
1900	736	124,680,087	169,402
1901	775	117,783,832	151,979
1902	720	100,504,267	140,978
1903	693	88,650,141	127,614
1904	732	82,014,410	111,426
1905	750	56,365,117	74,127
1906	739	67,978,000	91,986
1907	836	71,325,000	85,317
1908	879	70,278,000	79,952

SABOONTCHY.

Year.	Number of Productive Wells.	Total Production in Poods.	Average Production per Well.
1892	230	154,737,100	672,800
1893	224	146,288,674	648,600
1894	260	143,029,202	550,100
1895	281	151,331,605	538,546
1896	325	152,674,160	469,766
1897	386	166,928,593	432,457
1898	457	179,828,697	393,498
1899	543	230,757,289	450,750
1900	665	251,634,159	378,096
1901	780	295,254,315	378,531
1902	751	267,159,044	355,737
1903	747	230,454,593	304,306
1904	791	218,126,912	270,637
1905	730	139,241,074	185,088
1906	712	156,999,000	220,504
1907	873	184,023,000	210,793
1908	978	198,606,000	203,073

ROMANY.

Year.	Number of Productive Wells.	Total Production in Poods.	Average Production per Well.
1892	29	41,041,380	1,415,200
1893	33	73,156,364	2,216,500
1894	52	61,701,100	1,186,500
1895	62	111,408,645	1,796,913
1896	84	78,088,324	929,622
1897	103	96,702,454	912,287
1898	113	100,523,699	889,590
1899	138	98,581,782	714,360
1900	185	114,835,986	620,734
1901	213	124,156,817	582,895
1902	219	139,943,833	639,013
1903	221	119,952,259	542,770
1904	253	133,442,406	527,440
1905	245	87,273,202	356,217
1906	253	95,381,000	377,000
1907	278	89,588,000	322,251
1908	279	78,269,000	280,534

BIBI-EIBAT.

Year.	Number of Productive Wells.	Total Production in Poods.	Average Production per Well.
1892	20	33,262,900	1,663,150
1893	26	47,494,729	1,826,700
1894	27	33,785,249	1,251,300
1895	31	47,128,073	1,520,260
1896	35	69,855,123	1,995,860
1897	38	62,514.479	1,645,117
1898	48	96,526,783	2,010,972
1899	58	80,840,807	1,393,807
1900	112	109,207,063	975.000
1901	143	133,613,181	934.358
1902	135	127,433.285	943,950
1903	174	157.289.515	903,962
1904	222	181,140,766	815,499
1905	248	126,704,031	510,903
1906	250	127,689,000	510,756
1907	305	131,281,000	430,429
1908	358	119,633,000	334,170

Grosny Oil-Field.—A Russian oil-field which has not falsified the hopes of its pioneers is located on a ridge of hills near Grosny on the Northern Caucasus, where the first great gusher was struck by an Englishman, Mr Alfred Suart, in the early nineties. The Grosny field differs from those of Baku in the nature of the anticline, which is a sharp fold running in a north-west to south-east direction for over seven miles, and in the strata, which are more compact and less difficult to drill in. Many of the wells flow for a while at a rate of 300 to 600 tons daily, but they generally become more rapidly exhausted than those of Baku.

Table XVIII. gives the production of Grosny since 1896.

TABLE XVIII.—PRODUCTION OF GROSNY OIL-FIELD.

Year.	Production in Poods.	Year.	Production in Poods.	Year.	Production in Poods.
1896	17,200,151	1901	34,652,271	1905	43,057,000
1897	27,568,794	1902	34,072,271	1906	39,954,000
1898	17,716,899	1903	32,772,482	1907	39,424,048
1899	25,194,566	1904	40,095,331	1908	52,058,480
1900	30,687,948				

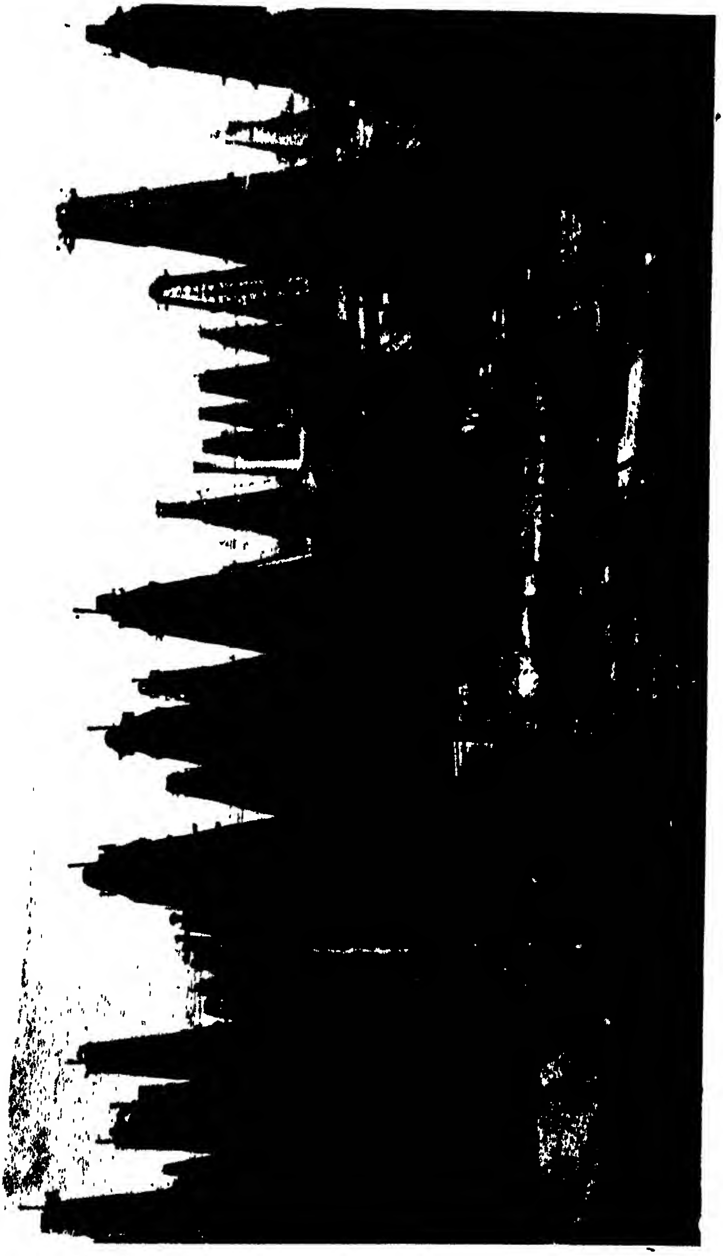

FIG. 3.—VIEW OF BIBI-EIBAT OIL-FIELD OF RUSSIA.

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Other Russian Oil-Fields.—Besides the great producing oil-fields of Baku and Grosny, there is a number whose importance is only eclipsed by the wonderful productivity of those first-named areas. Around the Baku oil-fields are many districts awaiting development, where the indications of oil fully justify operations, but with the exception of Binagadi, a few miles west of the Balakhany field, and Holy Island, off the end of the Apsheron Peninsula, little prospecting has been conducted. The production of Binagadi is given in Table XIX., but there are no available figures of the production from Holy Island, as the work is exclusively conducted by Nobels, which firm has drilled a number of wells, which yielded from 160 to 800 tons daily.

TABLE XIX.—PRODUCTION OF BINAGADI OIL-FIELD (IN POODS).

Year.	Quantity in Poods.	Year.	Quantity in Poods.
1895 - - -	...	1902 - - -	488,423
1896 - - -	28,816	1903 - - -	258,297
1897 - - -	197,462	1904 - - -	297,395
1898 - - -	227,730	1905 - - -	341,565
1899 - - -	213,386	1906 - - -	...
1900 - - -	406,517	1907 - - -	...
1901 - - -	468,118	1908 - - -	...

The Binagadi oil is piped to the railway, whilst the heavy Holy Island oil is mixed with residuum oil and sent direct to the River Volga with the Baku oils.

The Berekei oil-field, a few miles north-west of Derbent, on the Caspian Sea, attracted considerable attention in 1903 as a result of the striking of several flowing wells yielding as much as 300 to 700 tons daily, but water troubles, apparently unsurmountable, eventually drove nearly all the operators from the field after some 50,000 to 75,000 tons of oil had been obtained.

The island of Cheleken, south of Krasnovodsk, has yielded

a considerable quantity of oil rich in paraffin, and extensive developments are anticipated on this island, but water troubles have much impeded progress. The production of the island probably reaches 10,000 tons annually, but no official figures are published. In the Transcaspian provinces an oil-field has been opened up in the Ferghana district, where good producing wells have been completed and "paraffin" oils obtained. In 1906 the production of this field reached 64,000 tons.

Other fields which present a promising outlook and yield small quantities of oil are located near the Black Sea between Maikop and the Taman Peninsula, in the Ural district north of the Caspian, and in the Uchta district in the province of Archangel. On the Russian portion of the island of Sakalin oil is also said to exist in considerable quantities.

Dutch East Indies.—Oil-fields of immense value and great extent have been discovered and operated in the Dutch East Indian islands of Borneo, Sumatra, Java, where extraordinary results have been achieved in a short space of time. The oil is found in anticlinal folds with steep dipping sides, and the axes are generally characterised by a wonderful display of the natural phenomena which are usually associated in a less degree with petroleum. As in the other Eastern oil-fields the oil-bearing strata are of Tertiary age, and are generally associated with coal and lignite. In Borneo there are both asphaltic and paraffin oils in the same oil-field at different depths. Some of the Sumatra oils are especially rich in light products, and these have been largely sought for the production of spirit for the European market.

It is asserted by prospectors in the East Indian islands that there are hundreds, if not thousands, of square miles of oil-bearing land which can be remuneratively exploited when occasion demands. At present the East Indian oil trade is chiefly monopolised by the Royal Dutch Company, who acquired by amalgamation the Shell Transport and

Trading Company's interests after that latter concern had developed great fields in Borneo. The statistical data are very incomplete, but Table XX. gives an approximation of the East Indian production.

TABLE XX.—APPROXIMATE PRODUCTION OF DUTCH EAST INDIAN OIL-FIELDS (METRIC TONS).

Year.	Java.	Sumatra.	Borneo.	Total.
1901	82,000	410,000	61,300	553,300
1902	10,000	560,000	121,000	691,000
1903	9,700	650,000	144,000	781,000
1904	11,500	710,000	242,000	1,036,000
1905	...	...	...	1,158,000
1906	...	...	...	1,169,000
1907	135,500	404,800	638,400	1,179,000
1908	...	...	...	1,143,000

Austria-Hungary.—The oil-fields of Galicia in Austria-Hungary are really a continuation of the Roumanian fields, and, like the latter, lie on the flanks of the Carpathian Mountains. Many districts have been prospected with success, and oil-fields developed as a consequence, but operations have been centred at Boryslav and Tustanowice, in East Galicia, where deep drilling has revealed the existence of highly productive sources. The strata in the Boryslav district are so much disturbed and steeply inclined that drilling is exceedingly difficult, and a year may be occupied in sinking a deep bore-hole.

Boryslav oil is rich in solid paraffins, and it often partially solidifies as it flows from the wells, or is raised by the pumps. The wells are carried to depths of 3,000 to 4,000 feet, and frequently cost from £6,000 to £8,000.

Table XXI. gives the production of the Galician oil-fields in metric tons.

TABLE XXI.—PRODUCTION OF GALICIAN OIL-FIELDS OF AUSTRIA-HUNGARY (IN METRIC TONS).

Year.	Metric Tons.	Year.	Metric Tons.
1874	20,927	1892	89,871
1875	22,140	1893	96,331
1876	22,927	1894	132,000
1877	23,714	1895	214,800
1878	24,500	1896	339,765
1879	30,000	1897	309,626
1880	32,000	1898	323,142
1881	40,000	1899	321,681
1882	46,100	1900	326,334
1883	51,000	1901	452,200
1884	57,000	1902	576,000
1885	65,000	1903	713,330
1886	42,540	1904	827,117
1887	47,817	1905	801,796
1888	64,882	1906	760,448
1889	71,659	1907	1,175,975
1890	91,650	1908	1,754,022
1891	87,717		

Roumania. — The high prices obtained for crude oil during the last few years have not only led to the active development of the great proven districts of Bushtenari and Campina, but to extensive exploration and subsequent development of numerous new areas along the flanks of the Carpathian Mountains. No less than seventeen districts in the Prahova department, four in the Dambovitza, four in the Buzau, and ten in the Bacau departments have yielded petroleum, although the main supplies have been recovered from the Bushtenari, Campina, and Moreni districts of the department of Prahova. The oil is obtained on anticlinal folds following the Carpathian Mountains where strata of

Tertiary age are either brought to the surface or sufficiently near to permit of drilling. Some districts, as Campina, yield a petroleum with a paraffin base, whilst others, as Bushtenari, yield a normal, but light, asphaltic oil practically devoid of solid paraffins. The wells vary in depth from a few hundred feet to two thousand, and the yield often commences at 100 to 200 tons daily, falling off by degrees to 3 or 4 tons daily, although occasional wells in the Campina and Moreni districts have flowed at the rate of a thousand or more tons daily for a while. Roumanian oils are largely exported to adjoining countries by rail and along the Danube and to other European countries from Constanza on the Black Sea, to which port it is conveyed in tank waggons.

Extensive modern refineries have been built at Campina, Ploesti, and Bereasca, where petrol, spirit, illuminating oils, lubricants, and paraffin wax are prepared for home consumption and export. In 1905-6 over 65,000 tons of fuel oil (residuum) were used on the Roumanian railways.

Table XXII. gives the production in metric tons of the four departments of Roumania, from which will be gleaned the rapid development of the industry.

TABLE XXII.—PRODUCTION OF ROUMANIAN OIL-FIELDS (IN METRIC TONS).

Year.	Prahova.	Dambovitra.	Buzau.	Bacau.	Total.
1857	220	55	...	...	275
1858	330	166	...	...	495
1859	330	275	...	...	605
1860	385	715	...	88	1,188
1861	440	1,100	...	863	2,403
1862	550	1,100	...	1,576	3,226
1863	660	1,650	...	1,576	3,886
1864	825	2,200	...	1,566	4,591
1865	1,100	2,750	...	1,576	5,426
1866	1,100	3,300	...	1,515	5,915
1867	1,725	3,630	...	1,715	7,070
1868	1,989	3,850	...	1,861	7,700
1869	2,248	3,980	...	1,912	8,140

TABLE XXII.—PRODUCTION OF ROUMANIAN OIL-FIELDS (IN METRIC TONS)—*continued.*

Year.	Prahova.	Dambovitza.	Buzau.	Bacau.	Total.
1870	1,100	3,850	5,120	1,579	11,649
1871	1,608	3,750	5,467	1,695	12,520
1872	1,650	2,500	7,478	1,062	12,690
1873	2,750	2,200	7,518	2,000	14,468
1874	1,550	2,800	7,800	2,200	14,350
1875	1,600	3,000	8,200	2,300	15,100
1876	1,780	3,250	7,700	2,750	15,480
1877	1,800	3,200	7,600	2,500	15,100
1878	2,100	2,900	7,500	2,700	15,200
1879	2,500	3,100	6,900	2,800	15,300
1880	2,900	2,900	7,100	3,000	15,900
1881	3,500	3,000	7,400	3,000	16,900
1882	5,400	3,500	7,000	3,100	19,000
1883	5,700	3,500	6,900	3,300	19,400
1884	15,600	3,700	7,000	3,000	29,300
1885	12,800	3,600	7,500	3,000	26,900
1886	9,300	4,250	7,000	2,900	23,450
1887	9,500	5,000	8,000	2,800	25,300
1888	8,900	9,500	8,400	3,600	30,400
1889	10,500	15,000	10,100	5,800	41,400
1890	10,300	25,000	11,000	7,000	53,300
1891	11,500	38,000	10,500	7,900	67,900
1892	16,000	47,000	11,000	8,500	82,500
1893	17,000	35,000	9,500	13,000	74,500
1894	26,000	18,800	9,250	16,500	70,550
1895	37,140	15,440	9,040	18,380	80,000
1896	40,880	14,650	9,020	17,020	81,570
1897	69,300	15,500	7,000	18,200	110,000
1898	129,230	19,250	11,850	19,670	180,000
1899	187,100	23,000	18,900	21,000	250,000
1900	172,000	29,000	24,000	25,000	250,000
1901	233,000	17,000	6,000	13,000	270,000
1902	259,000	33,000	5,000	14,000	310,000
1903	345,913	22,469	5,920	10,000	384,302
1904	455,354	26,234	8,828	10,145	500,561
1905	568,289	24,703	12,904	8,974	614,870
1906	846,189	20,142	11,680	9,080	887,091
1907	1,077,871	32,314	9,927	9,185	1,129,297
1908	1,095,821	26,272	10,768	14,868	1,147,727

Central America—*Mexico.*—The republic of Mexico is destined to become a great oil-producing country in the near future. Under the direction of British and American capitalists, extensive oil-fields have been systematically pros-

pected and proved, and preparations are being made for distributing locally and exporting to Europe supplies from these fields. The Mexican Petroleum Company have developed important oil-fields with great potentialities near Tampico, Laguna de Temiahua, and Tuxpan, where large flowing wells have been struck. Messrs Pearson & Son have tested and developed extensive and valuable oil-fields at Minatillen in Veracruz, and in Tabasco, and many of the Mexican railways are already being supplied with fuel oil.

Whilst some of the oil is fairly rich in spirit and illuminating products, the majority is of a heavy description chiefly suitable for fuel purposes. No figures of production of oil are obtainable, but the output in 1907 was estimated at fully 150,000 tons, and in 1908 one gushing well alone in the San Geronimo field, 75 miles from Tampico, was estimated to have yielded 400,000 tons of oil, although it was mostly consumed by a fire which broke out.

South America.—Although there are numerous encouraging indications of petroleum in South America, there was in 1908 only one republic, Peru, which was producing oil in any important commercial quantities. There are extensive and important untouched oil territories in Venezuela, Colombia, Ecuador, and small quantities of oil have been obtained from several localities in the Argentine and in Chili and Bolivia.

Peru.—The oil-bearing belt of Peru runs for several hundred miles in the almost rainless region from the Ecuadorian frontier in the north to beyond Payta in a southern direction, along which strip there are three important oil companies operating, two of which, the London and Pacific Petroleum Company and the Lobitos Oil-Fields Limited, are English. The oil-bearing formations are of Tertiary age, and the oil has exclusively an asphaltic base. The three areas of Northern Peru operated for oil are Negritos, 40 miles north of Payta; Lobitos, 60 miles north of Payta;

and Zorritos, a few miles south of Tumbez. Both crude and residuum oils are largely transported to Chili for use in the nitrate fields, and in Peru some of the railways use oil fuel.

Table XXIII. gives the Peruvian production for the last few years :—

TABLE XXIII.—PRODUCTION OF PERUVIAN OIL-FIELDS (IN TONS).

Year.	Negritos.	Lobitos *	Zorritos.	Titicaca.
1898	13,000	...	11,080	No figures available.
1899	19,500	...	14,400	
1900	29,000	...	16,630	
1901	32,000	...	12,100	
1902	27,500	...	9,600	
1903	36,000	...	7,930	
1904	39,500	...	8,000	
1905	45,000	2,000	6,090	
1906	44,000	25,000	6,860	
1907	53,000	35,000	10,580	
1908	72,500	50,000	...	

* Lobitos production approximate only.

Another oil-field has been prospected about 8 miles from Lake Titicaca by the Titicaca Petroleum Company. Mr Campbell M. Hunter, who visited the field in 1908, reports that an anticline extends in a direction 40 degs. west of north, but the ground appears to be much disturbed. Some ten wells have been drilled with varying results, but although the initial production sometimes exceeded, it is said, 150 tons daily, the output fell rapidly. The oil is unlike that of the northern oil-fields of Peru, as it contains some 5 per cent. of paraffin wax, and 40 to 50 per cent. of kerosene.

Germany.—There are two oil-fields in Germany which produce a limited quantity of heavy petroleum. In the Wietz field of Hanover, wells are drilled to depths between 500 and 1,500 feet, but operations are impeded by quantities

of salt water which permeate the beds near the oil-bearing strata.

The only other oil-field in Germany is in the province of Alsace.

TABLE XXIV.—PRODUCTION OF GERMAN OIL-FIELDS (IN TONS).

Year.	Production in Tons.	Year.	Production in Tons.
1880	1,309	1895	17,051
1881	4,108	1896	20,395
1882	8,158	1897	23,303
1883	3,755	1898	25,987
1884	6,490	1899	27,027
1885	5,815	1900	50,375
1886	10,385	1901	44,095
1887	10,144	1902	49,725
1888	11,920	1903	62,680
1889	9,591	1904	89,620
1890	15,226	1905	78,869
1891	15,315	1906	81,350
1892	14,257	1907	106,379
1893	13,974	1908	141,900
1894	17,232		

Japan.—In the province of Echigo, Japan, an oil-field has been developed in a primitive way for centuries, but the introduction of American methods of drilling in recent years has enabled deeper sources to be tapped, and an increasing production has resulted.

Table XXV. gives the production of Japan since 1875.

TABLE XXV.—PRODUCTION OF PETROLEUM FROM JAPANESE OIL-FIELDS SINCE 1875 (IN U.S. BARRELS).

Year.	Quantity.	Year.	Quantity.	Year.	Quantity.
1875	5,460	1887	34,210	1899	534,900
1876	9,215	1888	44,750	1900	865,970
1877	11,442	1889	62,950	1901	1,111,000
1878	21,395	1890	61,380	1902	1,198,300
1879	28,040	1891	63,180	1903	1,203,900
1880	30,450	1892	82,390	1904	1,401,900
1881	20,100	1893	106,380	1905	1,472,804
1882	18,595	1894	171,540	1906	1,705,776
1883	24,460	1895	168,960	1907	1,994,207
1884	33,350	1896	235,960	1908	2,061,000
1885	34,095	1897	260,920		
1886	45,490	1898	318,860		

The Japanese oil is chiefly found in sandstones of Tertiary age interstratified with beds of slate or shale. The wells are drilled to depths of from 600 feet to 2,000 feet, according to the locality, and a large deposit of peat covering part of the field constitutes a cheap source of fuel. The oils contain from 35 to 40 per cent. of lamp oils, and some contain solid hydrocarbons.

Italy.—There are three districts in Italy where some oil-fields have been tested to a limited extent, namely, the Emilia in Lombardy, the Pescara valley in Central Italy, and especially the Livis valley, also in Sicily. The production is given in Table XXVI.

TABLE XXVI.—PRODUCTION OF PETROLEUM (ITALIAN OIL-FIELDS).

Year.	Production in Metric Tons.	Year.	Production in Metric Tons
1897	1,932	1903	2,486
1898	2,015	1904	3,543
1899	2,242	1905	6,123
1900	1,683	1906	7,451
1901	2,246	1907	7,643
1902	2,633	1908	...

The oil from the Italian fields is of exceptional high grade, often having a specific gravity of only .780, and yielding a high percentage of spirit and illuminating oils, but the ground is said to be much broken up, rendering drilling very difficult.

Africa.—No oil-field of any importance has yet been located on the African Continent, although there are many localities where indications justify the general belief that petroleum in large quantities exists. For many years an oil-field in the departments of Algiers and Constantine in Algeria has been worked, but the strata are much disturbed, and the petroleum is distributed irregularly. In Egypt a prolific well has recently been drilled near Gebel Genesah, on the Red Sea, about 150 miles south of Suez, and developments will be watched with general interest, as indications extend over a wide area. Many abortive attempts have been made to strike oil in South Africa, and there are many who still believe that oil does exist in quantities. In both East and West Africa oil prospecting has been conducted, and in Madagascar some particularly promising territory is likely to be tested at an early date.

Leasing of Oil Lands.—It is only within recent years that the leasing of oil lands has become to be considered as important as other mining leases, and special laws have been framed in some countries to deal with the subject. The considerable public danger arising from oil-field operations, if allowed to proceed without restriction and without regard to public property, has led to widespread destruction of property with loss of life time after time, and it is essential that stringent laws should regulate the operations in rich oil-fields where the wells are located close together, and large eruptions of oil and gas are frequent.

The general trend of legislation is to fix a minimum area which shall constitute a separate lease; to establish a

minimum distance from the boundaries of properties within which wells may be drilled, and to define a minimum radius around dwellings and boiler-houses where wells may be drilled. The minimum area of a plot is approximately fixed by the two latter conditions where it is customary to have employees' quarters and power installations on the property, but the gradual transference of town sites to the outskirts of the important long-lived oil-fields, and the increased use of electrical power in some fields diminishes the importance of those points. The establishment of a minimum distance from the boundaries of properties in congested oil-fields like those of Baku, Bushtenari, and Spindle Top, is only appreciated when the permanent injury that good producing wells may sustain by incautious operations of negligent neighbours is known, explanations of which dangers are described on p. 260. The incomplete exclusion of water from a well, or the employment of a flushing process for drilling, or in fishing for lost tools in a well in close proximity to a good producer may cause the total ruin of the producing well and the loss of anything up to several hundred tons of oil daily.

In the majority of the oil-fields of the United States where experience has shown that one well is sufficient to exhaust several acres of land, the conditions themselves establish a minimum of area, and no danger can result from such wide distribution; but in some of the Californian, Texan, and Mid-Continental oil-fields, land has been cut up into small patches, and wells have been sunk side by side by rival proprietors, with the inevitable result of occasional conflagrations which destroyed properties wholesale and consumed thousands of tons of oil, and of the ruin of many wells through the neglect of the less cautious operators to exclude water in their haste to be first down to the oil source.

In the Baku oil-fields no property can now be independently worked with an area of less than a dessiatine (2.7 acres), so that proprietors of plots of less area have to make arrange-

ments with neighbouring operators if they wish their land exploited.

Another feature of leasing has caused delays and often injury to the industry, namely, the difficulty of discovering the rightful owners of lands when oil has been struck in a district where the lands have little value for agricultural pursuits. In the early days of the Russian and Roumanian oil industry, innumerable owners appeared immediately oil was found, and capitalists desiring to acquire lands were compelled to pay money to a host of claimants, and probably after all discover that not one had any legal claim. So scandalous became the conduct of the Roumanian peasants that the Government was compelled to protect would-be operators by a registration law, under which the landowners were compelled to register their ownership and notify any transfer or sale of lands or oil rights. In Russia, also, owners of land in the vicinity of oil-fields were forced to prove the validity of their titles, but so much litigation ensued between the Government and claimants over some plots in the Romany district of the Baku field that it was only after millions of tons of petroleum had been extracted and sold that the claims of the Government were proved. The Russian Government, however, treated the occupiers with consideration, allowing them to retain the property on a royalty basis, and charging a moderate lump sum as compensation for oil already extracted.

In some countries the oil lands are chiefly owned by the Governments, or where the lands are sold or leased the Governments have retained the mineral rights for separate disposal, but generally the mineral rights are included in the original sales or leases of the lands, and the proprietor can make his own arrangements. In South American republics and Spanish countries, where the old Spanish mining laws are left almost intact, petroleum, though not particularly mentioned, is treated as some other minerals, and prospecting rights or *pertenencias* are secured for a nominal sum by an application to the nearest official of the Mining Department.

A full mining right over a certain selected area may be subsequently secured by a further declaration of discovery and the payment of larger fees and a rental.

Most of the United States oil-fields were originally purchased for agricultural pursuits before the discovery of oil was made, and the owners have leased the petroleum rights to producers on either a royalty basis or for a direct payment or a combination of both. *Prospecting* rights are often secured from land proprietors for nothing, or for a purely nominal sum, a royalty of 5 to 10 per cent. being payable when oil is produced. Where lands have been practically proved to be oil-bearing by neighbouring operations, the proprietors usually demand a royalty of one-tenth to one-eighth of the net output, and if the adjoining lands have proved specially prolific, a cash payment in addition is often demanded. As an example might be mentioned the oil lands of Illinois, where, in 1907, a bonus of £30 to £40 an acre was demanded for oil leases in favourable localities in addition to an eighth royalty.

In such locations as Spindle Top, Texas, where a feverish excitement, only comparable with gold-field rushes, was displayed by speculators to procure well-placed lands, large sums of money were paid for areas scarcely large enough to erect a derrick and rig, but *boná-fide* operators took no part in such speculation.

Realising the value of an oil strike on an estate, it is not unusual for proprietors to offer a bonus of the oil rights over many acres to a prospector who will undertake to sink a few trial wells on a farm in likely territory. In nearly all cases the royalty is payable on the net production, *i.e.*, the amount of oil ready for sale after deducting all oil used as fuel on the works, or for other field purposes.

The Canadian farmers of Ontario and the peasant proprietors of Roumania and Galicia usually dispose of the oil rights on their farms at a royalty of 10 per cent., and many derive a handsome supplementary income from this source.

In Russia the oil lands are largely held by the Government, which grants prospecting licences in new areas on nominal terms over blocks of 100 acres (ziavkas), from which the lessee can select 27 acres and develop on a royalty basis. Some of the best original Baku lands were imperial grants to distinguished Russian soldiers, and others were leased in 27-acre blocks for a fixed annual payment of 10 roubles a dessiatine (7.8 shillings an acre), increasing ten times every ten years; but subsequently lands within proved areas were leased by auction on either a fixed sum per pood raised or a percentage of the net production. Considerable speculation arose at the auctions at periods of high prices, and the Government was often constrained to cancel leases or to modify the terms at periods of depression, when the fulfilment of the terms of the lease often spelt ruin to lessees. In the Baku oil-fields the cash royalties vary between 1 copeck and 12 copecks per pood (1s. 4d. to 15s. 9d. per ton), and from 25 to 50 per cent. in kind, but the high royalties are payable on proved lands in specially prolific areas where a single well has at times meant a fortune to the owner.

Some of the original oil leases at nominal rentals have changed hands for fabulous sums, as, for instance, Plot XIX. Bibi-Eibat, with an area of only 27 acres, which was purchased by an English company for £500,000 in 1895. In the Grosny oil-fields, where the lands belong to the administration of the Cossack Army of the Don, blocks of 27 acres or thereabouts were originally leased to producers at a fixed royalty of 1 copeck per pood (say 1s. 4d. per ton) for a limited number of years, after which new terms could be imposed by the authorities if they chose. In certain cases the expiration of the lease of some of the best plots led to the imposition of a percentage royalty.

In India special laws for the leasing of oil lands have been passed, and the acquisition of Government oil lands thereby simplified, and the royalty fixed at 10 per cent.

There are many important points raised when a petroleum

lease is issued, as naturally the owner of the land in transferring his rights wishes to ensure the fulfilment of the terms without imposing burdensome obligations on the lessee. The lessor's rights are usually protected by the stipulation of a minimum royalty after a definite period allowed for exploration, so that in the event of no oil being found within the prescribed free period, or the production being too small to leave a margin of profit under the conditions of the lease, the lessee may abandon the land or open negotiations for new terms. It is also to the lessor's interest to secure the greatest development of his lands, and this is sometimes encouraged by the introduction of a scale of royalties whereby with each defined increase of production, within certain limits, the royalty per unit is reduced. Both the above clauses have been incorporated in Russian Government leases, the former being often a nominal sum only.

Another important question often raised in oil leases is the form the royalty should take, whether in kind or in value. To an ordinary landowner or farmer the oil would be of no use, and there might be no means of disposal; but, on the other hand, there is the difficulty in some places of arriving at a value for the crude material. In large oil centres there is never much difficulty, as there is usually some kind of official or recognised quotation, but in new oil regions the oil may for a time have a nominal value only. The difficulty is sometimes overcome by fixing a constant value to the oil per unit of weight or volume, when the settlement of royalty causes no trouble, but there is then the unavoidable speculative element of the transaction which sometimes arouses trouble when one side or the other is making a greater profit than was originally estimated. In any case it is a practical impossibility to attempt to arrive at a value for crude oil from the value of refined products, and other means, such as arbitration or acceptance of an exchange value, must be agreed upon where the crude oil is not sold direct, but treated in a refinery by the producer.

Below is an example of a typical lease made by farmers in the Ontario oil-fields of Canada:—

THIS LEASE, made the day of A.D., between of , in the County of and Province of Ontario, farmer, hereinafter called the Lessor, of the first part, and , hereinafter called the Lessee, of the second part. In consideration of the agreements herein contained, the lessor does hereby grant and lease unto the lessee, for the term of five years, and so long thereafter as oil or gas is produced from the land leased in paying quantities, the exclusive right to drill for and produce petroleum and natural gas, and the right to conduct all operations necessary for the production, storage, and transportation of oil or natural gas, with the right to use water and gas (if found) for the necessary engines, and to remove all machinery, fixtures, &c., placed by the lessee on the premises, namely: , in the Township of , County of , Province of Ontario, being acres more or less. No wells to be drilled within feet of buildings without lessor's consent. The lessee to deliver to the lessor on the premises, free of cost, the one-tenth part of all petroleum produced and saved from the premises, and to pay one hundred dollars ($100) per annum for each gas well from which the gas is marketed for lighting any village, town, or city. If the lessor shall request it, the lessee shall bury all oil and gas lines below plough depth.

Lessee to pay compensation for any actual damage to crops or improvements caused by operations, to keep all gates closed and fences as found, and to pay all taxes rated on any property or effects he may place thereon.

This lease to be null and void and no longer binding on either party if operations for drilling are not commenced on the premises within days from this date, unless the lessee shall thereafter pay yearly to lessor twenty-five cents (25¢) per acre for delay.

It is understood between the parties to this agreement that all the conditions between the parties hereunto shall extend to their heirs, executors, administrators, and assigns.

Lessor to have free use of gas (if found) for household purposes on the premises during said terms.

SIGNED and sealed by

The following is an example of an oil and gas lease used in the Pennsylvanian oil-fields:—

THIS INDENTURE, made the day of A.D. 190 between of the of County of and State of , lessor, and , lessee.

WITNESSETH, that the lessor, in consideration of Dollars, the receipt whereof is hereby acknowledged, being rental in advance for

months from the date hereof, does hereby grant, demise, and let unto the said lessee, all the oil, gas in and under the following described tract of land, with covenant for the lessee's quiet enjoyment of the term, and that lessor has the right to convey the premises to the said lessee; together with the exclusive right unto the lessee to operate and drill for petroleum and gas, to lay and maintain pipe lines, to erect and maintain telephone and telegraph lines, and buildings convenient for such operations; and the right to use water and gas from said lands in operating same, and right of way over same for any purpose, and right of ingress, egress, and regress for such purposes, and of removing, either during or at any time after the term hereof, any property or improvements placed or erected in or upon said land by said lessees, and the right of subdividing and releasing all or any part of all that tract of land situate in the of County of and State of , and bounded and described as follows, to wit:—

On the North by the lands of
on the East by the lands of
on the South by the lands of
on the West by the lands of
containing acres, more or less.

TO HAVE AND TO HOLD unto and for the use of the lessee for the term of years from the date hereof, and as much longer as oil or gas is produced in paying quantities, yielding to the lessor the one-eighth part of all the oil produced and saved from the premises, delivered free of expense into tanks or pipe lines to the lessor's credit.

Should a well be found producing gas only, then the lessor shall be paid for each such gas well at the rate of Dollars for each year, so long as the gas is sold therefrom, payable quarterly while so marketed.

Lessee agrees to complete a well on said premises within months from the date hereof, or pay the lessor Dollars each three months in advance from the day of until said well is completed or this lease surrendered. And the drilling of such well, productive or otherwise, shall be full consideration to lessor for grant hereby made to lessee with exclusive right to drill one or more additional wells on the premises during the term of this lease. Lessor is to fully use and enjoy said premises for the purpose of tillage, except such parts as may be used by lessee for the purpose aforesaid. Lessee is not to put down any well on the lands hereby leased within ten rods of the buildings now on the said premises without the consent of the lessor in writing. Lessor may, if any well or wells on said premises produce sufficient gas, have gas for domestic purposes for one family, the lessor paying for connections at such points as may be from time to time designated by lessee.

The above rental shall be paid to lessor in person or by check deposited in post office direct to . And it is further agreed that lessee shall have the right to surrender this lease upon the payment of Dollars, and all amounts due hereunder and thereafter shall be released and discharged from all payments, obligations, covenants, and

conditions herein contained, whereupon this lease shall be null and void, and that all conditions, terms, and limitations between the parties hereto shall extend to their heirs, successors, personal representatives, and assigns.

Lessor agrees that the recordation of a deed of surrender in the proper County and a deposit of all amounts then due hereunder to lessor's credit in Bank shall be and be accepted as full and legal surrender of lessor's rights under this lease.

IN WITNESS WHEREOF. We, the said parties hereto, have hereunto set our hand and seals the day and year first above written.

CHAPTER II.

GEOLOGICAL STRUCTURE AND PETROLOGICAL CHARACTER OF PETROLEUM FIELDS AND THEIR BEARING UPON THE DISTRIBUTION OF PETROLEUM IN THE STRATA.

Geological Conditions necessary for the Formation of Petroleum—Geological Conditions affecting the Accumulation and Preservation of Petroleum—Subterranean Movements of Petroleum—Causes of Pressure—Character of Oil-Bearing Strata—Area influenced by Productive Wells and the Distance that should separate Individual Wells—Production and Life of Oil-Fields—Selection of Sites for Drilling—Oil-Field Waste.

Geological Conditions necessary for the Formation of Petroleum.—All sedimentary strata, to which primary petroleum deposits are exclusively confined, were deposited horizontally or practically so, and the present deformation imparted to the beds is due to subsequent terrestrial disturbances. The similarity in many respects of the majority of petroleum-bearing strata of the same class enables one to judge approximately the essential conditions that characterised the formation of petroleum in many fields. The material from which the main supplies of petroleum were produced was evidently deposited with sediment in water of medium depth, and generally in salt water, as proved by the occurrence of fossilised remains of a salt-water fauna or flora in the strata, but in nearly all cases there were periodical variations of level which caused intermittent depositions of deeper water sediments, such as extremely fine sands, clays, or marls, and shallower water sediments, such as pebbles and shingle. In some fields the alternations of sands and clays are so rapid yet quite distinct, that it may be surmised that climatic conditions and variable currents were more likely for a time the

influencing factors than movements of land; yet in other cases beds of lignite at intervals indicate the periodical sinking movements of the land with occasional long periods of quiescence. For the production in nature of such immense supplies of petroleum as are often found concentrated in certain areas it is certain that the strata in which it was formed, or in which it accumulated as produced, must have been of a porous nature, and sands are obviously the most common and natural media for such storage, although some vesicular limestones constitute important reservoirs.

A second necessary condition for the production of petroleum is an impervious covering to the porous stratum in which the chemical actions resulting in the formation of petroleum take place. If the products of decomposition of deposited organic material were able to escape as formed, water, either with or without salts of lime or iron in solution, would replace the lost products, or a dry porous stratum would result, and no petroleum could be produced.

Petroleum-bearing strata are invariably overlaid by impervious beds, usually shales, which have not only doubtless played a considerable part in presenting the conditions essential to the formation of oil, but also in its subsequent retention during all the earth movements which usually followed prior to its ultimate accumulation in certain locations. The clays themselves which lie in proximity to oil-bearing sands are often impregnated with petroleum and are darkened to a considerable degree, and considering the impervious character of the clays, one is more disposed to attribute its occurrence to formation in the clay than to introduction from the sands, notwithstanding the well-known affinity of clay for petroleum, in confirmation of which view may be mentioned the well-known bituminous character of the Kimmeridge and Lias clays of England. Often the clay or indurated clay shales separating petroleum-bearing beds of sand are very arenaceous, and it is only natural to surmise that the conditions attending the accumulation of the organic matter producing the

petroleum should have persisted, although perhaps in a less pronounced degree, through the periods of clay deposition preceding and succeeding the deposition of the sands. In many cases, however, there are no traces of petroleum or gas in the clays or shales dispersed amidst an oil-bearing series, neither are they discoloured nor carbonaceous.

It is probable that a third circumstance was often contributory to the production of petroleum, namely, high salinity of the water. All water associated with petroleum strata is highly impregnated with salt, much more so than ordinary sea water, and as this circumstance is so universal it seems highly probable that the antiseptic property of the salt water was instrumental in delaying decomposition of deposited organic matter until the clays were deposited and the material sealed, and in determining to some extent the nature of the resulting decomposition. In Roumania thick deposits of rock salt occur in the petroleum belts, and in Galicia and Texas beds of rock salt occur amidst the oil series, thus proving that conditions existed about that period for the deposition of salt from water over a large area; and in many fields salt has been produced on a commercial scale by evaporating water pumped from wells sunk in oil strata. Salt lakes are common in oil districts, and salt is often collected in the dry season from basins where it has crystallised out on the concentration by evaporation of rain water which has dissolved salt from the outcropping strata (see Chapter III.).

Porous sedimentary strata are naturally saturated to their full capacity with water when deposited, and as water is practically incompressible one must conclude that there would be no space for petroleum unless the water were displaced or the decomposition of other sedimentary matter yielded the necessary space for the produced liquid and gaseous hydrocarbons. As there are many strong arguments in favour of the view that petroleum is generally indigenous to the strata in which it is now found, it is obvious that something must have been present in large quantities in the original sediment,

and that the material has partially or entirely been replaced by petroleum. The various theories expounded to account for the origin of petroleum are considered in Chapter IV.

Geological Conditions affecting the Accumulation and Preservation of Petroleum.—It is now generally admitted that oil, whilst occasionally having an obviously adventitious origin, was more often formed in the beds in which it is found when they were horizontally disposed; but as petroleum and gas are fluids, and obey the laws of fluids, their present distribution is largely the result of terrestrial disturbances which have from time to time forced the containing strata into irregular contortions. Successive earth movements, especially in the neighbourhood of mountain ranges, have not only given the beds an inclination in certain directions, but have caused the strata to assume wave-like forms in adjusting themselves to the crushing forces.

The ordinary anticlinal and synclinal structure is a normal consequence of such forces, but rarely is this simple structure unaffected by secondary forces in other directions or by numerous faults, which not only complicate the structure, but have an important bearing upon the distribution of the fluids the beds contain. Apart from the effect of such structure on the segregation of petroleum, it is these crushing forces which have brought the productive beds from great depths sufficiently near to the surface to disclose to the geologist their presence, and to enable them to be cheaply reached by means at the disposal of man. The thrusting upwards of thousands of feet of sedimentary strata into an inclined or vertical direction has also enabled direct measurements of the thicknesses of beds to be made, depths of strata to be learned, the relative age of the strata to be ascertained, and key horizons to be noted for identification during drilling.

The greatest service rendered by nature, apart from actually disclosing the existence of the beds, is the con-

centration of petroleum in certain spots where operations can be centred. When geological strata are forced into undulations, the fluid contents of porous beds obey the laws of gravitation, and if water, petroleum, and gas are together present, as is usual, in petroliferous beds, there is a tendency for them to separate and distribute themselves according to their respective specific gravities. Gas would as much as possible disengage itself from the fluid and rise to the highest point in the beds, whilst water on the other hand would endeavour to displace petroleum and find a resting-place as low down as possible. Provided, therefore, there were fair continuity of a porous stratum over a large area covered by several anticlinal and synclinal folds, there would be a tendency for the water, if present, to displace the oil and gas and accumulate in the synclinal basins, forcing the lighter petroleum and gas into the anticlines. Such separation in sandstones, limestones, and compact sands would probably occupy a long time, but that such separation has taken place there is unmistakable evidence.

When there is a series of continuous petroleum-bearing strata covered by impervious seams of clay, forced into a succession of gentle undulations which are not severely fractured, the partial separation and segregation of the fluid contents has led to the accumulation of vast sources of petroleum in the axial summits of the anticlines, and it is in such locations that the greatest oil-fields of the world are located. Often the concentration to certain points is further aided by subsidiary or secondary undulations or arrested uplifting of the axis of the anticline, causing the formation of dome-shaped areas, to the apex of which the fluid from all points round tends to concentrate. Such formations existed at Beaumont, Texas, and at Bibi-Eibat, Baku, where some of the greatest producing wells ever known have been struck, and where many of the early wells spouted with prodigious force for a while.

The anticlinal structure plays a very important part in

the segregation of petroleum throughout the world, and it is possible that its influence is even greater than that already described. It is rare that such violent earth movements as those causing the curvature of beds into chains of inclined strata, especially when the inclination is steep, are effected without considerable dislocation of the beds in the form of faulting or fissuring, and such dislocation permits a wider and more irregular distribution of petroleum and gas than originally prevailed. Porous beds may become charged with gas or petroleum or both, which were previously uncontaminated with hydrocarbons, or perhaps saturated with water; in fact, there is every reason to believe that where suitable conditions exist, beds of an age later than the true oil horizons do become charged with petroleum and gas, and become prolific sources of supply.

Some of the great gas wells of West Virginia have at first indicated a high closed pressure, but a steady increase of pressure has been noted until a maximum was only recorded many days after the completion of the well. This has generally been attributed to the impregnation of other porous strata above the gas formation, the natural earth pressure only being reached in the well when these upper seams to which the gas could find access were saturated as much as water would allow or natural absorption could proceed. This phenomenon conclusively illustrates the manner in which porous strata above oil or gas horizons could be permeated with oil or gas through the medium of fissures following earth movements.

The early development of some of the so-called Pennsylvanian oil-fields where great gas pressures were encountered is reported to have led to a complete change in the distribution of the oil, enabling wells to be sunk with success where there was previously no oil. This phenomenon is not difficult to understand where great volumes of gas become enclosed in definite areas, forcing under certain circumstances the liquid contents of the beds to other situations from which it returns

by gravitation to re-establish subterranean equilibrium after the gas has escaped. Some old operators assert that such a redistribution of petroleum occurred in parts of the Balakhany-Saboontchy oil-field of Baku, productive wells having been struck in parts of the field where previous to the active development of the field no oil had been encountered. (See also p. 56 on "Subterranean Movements of Oil.") In any case there is a great probability that some of the upper water-bearing sands of that field, which were nearly exhausted of water by general development, ultimately become charged with petroleum when oil under great pressure was impelled upwards through faulty casings from deeper sources.

Some of the yellow surface sands of the Baku oil-fields became so saturated with petroleum from surface soakage that they have for years been a fruitful source of production to men who work them with shallow shafts, for which concessions they often paid heavy rentals to the proprietors of the land.

The ideal structure of a broad anticlinal arch with unbroken axis, completely covered by impervious clays or shales, and

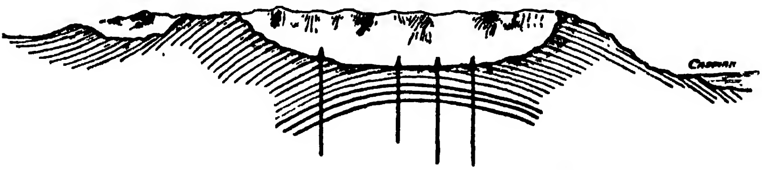

FIG. 4.—Regular Anticline with gently sloping sides as Bibi-Eibat.

with only slightly inclined strata on either side (as in Fig. 4), is only occasionally met with in nature, as usually the anticlines expose a considerable amount of outcropping beds on the flanks (as in Fig. 5), the central portion only having an

FIG. 5.—Oil-Field Structure as occurring in Parts of Caucasus, Roumania, and in California.

unbroken or only fissured capping. Most anticlines, too, have unequal slopes, the beds on one side being usually much more steeply inclined than the other. Such is the case in the Grosny field of Russia where the beds are almost vertical on the northern side, and have a 20-degree dip on the south, and the Burma oil-fields of Yenangyat, where there is a vertical inclination on the east of the anticline and

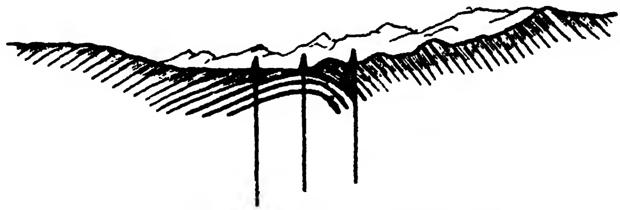

FIG. 6.—Anticline with Unequal Slopes as Bushtenari Field, Roumania.

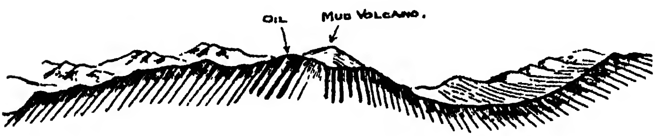

FIG. 7 —Sharply Inflected Anticline with Fractured Centre.

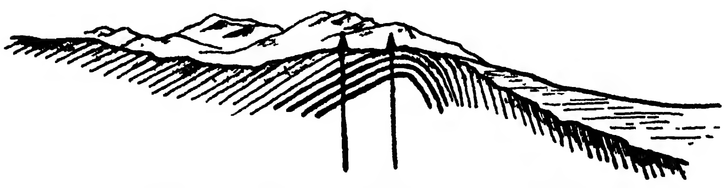

FIG. 8.—Anticline with Steeply Inclined Beds to One Side, often Faulted and Disturbed.

a 20-degree dip on the west. In Bushtenari, Campina, and other fields in Roumania the same unequally dipping flanks are usual. In Campina the dip is about 75 deg. in the north and 35 deg. in the south. In Bushtenari the dip to north is about 45 deg., and 15 to 20 deg. to south.

Many of the anticlines are so sharp that the beds are almost vertical near the crest, or, at least, so steeply inclined

that the oil-bearing strata can only be penetrated at a workable depth over a width of a few hundred yards. Such anticlines (as in Figs. 7 and 8) are seen at Grosny in Russia, in Roumania, Borneo, Burma, and California. In such cases the oil-fields extend in long narrow lines across the country for miles, drilling being confined to a narrow strip outside which the wells become much more expensive on account of increased depth. In the Whittier oil-field of Los Angeles County, California (Fig. 10), the wells are sunk in almost

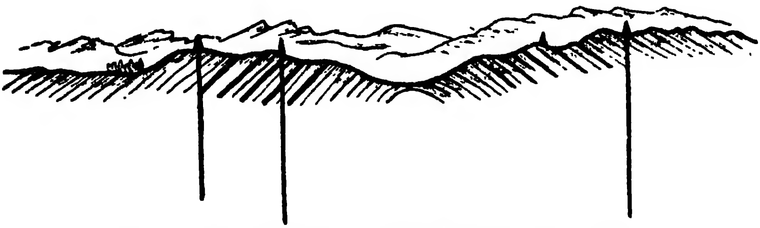

FIG. 9.—Common Structure of Oil-Field with Broken Crest.

vertical strata for miles in a narrow straight line over hills and valleys.

The axes of many anticlines which bring oil-bearing strata near the surface are indicated by the occasional occurrence of

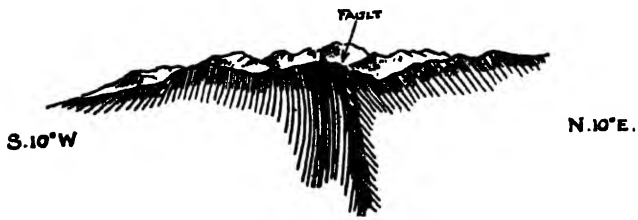

FIG. 10.—Section of Whittier Oil-Field of California, where Wells Sunk in Vertical Strata.

mud volcanoes and exudations of petroleum and gas through fissures, but often there are periodical eruptions of considerable violence which cause the disturbance of many acres of ground at weak spots when the gas pressure exceeds the overhead resistance. Such phenomena are fully described

PLATE IV.

FIG. 12.—WHITTIER OIL-FIELD OF CALIFORNIA.

Showing wells sunk in almost vertical strata and general appearance of many Californian oil-fields.

[*To face page* 52.

on pp. 96-99. These occurrences are generally specially prevalent where there is a disturbed area due to a deflection in the strike of the anticline.

Whilst the anticlinal structure is conducive to the accumulation of large supplies of petroleum, and such conditions characterise many of the greatest oil-fields of the world, such is not essential, as there are many highly productive oil-fields where anticlinal structure is absent. Petroliferous strata which have a fairly constant low dip in one direction, to all practicable depths, often outcrop on the surface for miles, and such beds, penetrated at a depth of several hundred feet by the drilling of wells to one side of outcropping sands, often yield remunerative supplies of petroleum, although the outcrops exhibit no excessive impregnation with petroleum. Such conditions are common in California, in Roumania, and in the Caucasus, and especially in Peru (Fig. 11), where all the

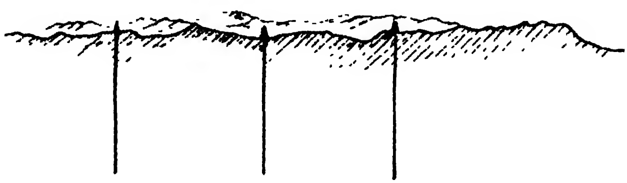

FIG. 11.—Oil-Beds with Regular Inclination in One Direction.

operated fields of Negritos, Lobitos, and Zorritos show this peculiarity. Even in the Appalachian oil and gas fields where the anticlinal theory applies well in practice, there are numerous examples of oil and gas being found in the base of synclines where the beds were not saturated throughout with water.* Whilst generally there is a distinct inclination of 15 to 70 deg., there are productive strata which have such

* See "Oil and Gas Fields of Greene County," by Stone and Clapp, U.S. Geological Survey, 1907; also see "Steubenville, Burgettstown, and Claysville Quadrangles Oil and Gas Fields," by Griswold and Munn, U.S. Geological Survey, 1907.

a slight dip that they may for all practical purposes be considered horizontal over a wide area. Such is the inclination of the Trenton limestone of Ohio and Indiana, which has a dip of only a few feet per mile, and has yielded millions of tons of petroleum of the highest grade.

In certain cases, where intrusive dykes have pierced oil-bearing strata at a recent date (geologically speaking), the distribution of petroleum has been modified, and may be almost independent of structural features in the sedimentary rocks. Definite areas may be isolated by volcanic dykes which arrest the movements of oil in certain directions where, unrestricted, the oil would gravitate or be transported by water; and in the Mexican oil-fields Dr Day considers that the basalt dykes which intersect the strata play an important *rôle* in the distribution of petroleum.*

The importance of the anticline has always been recognised in the search for new oil-fields and in the selection of drilling sites, but its relationship to the concentration of oil should not be overrated, for in many oil-fields supplies of petroleum have been obtained far down the flanks towards the synclines, whilst there is no evidence to prove that the synclines adjoining many important oil-fields are not oil-bearing. In most cases the anticlinal inflection is solely responsible for bringing the oil-bearing series sufficiently near the surface to indicate by characteristic phenomena the presence of petroleum, and to allow the beds to be reached by drilling appliances. Outside a certain limit indications of petroleum are concealed by strata of a newer period, and the inclined beds usually lie at too great a depth to be reached by drilling on a commercial scale, consequently initial operations are almost exclusively confined to a strip of territory in the direction of the axis of the anticline where the oil-beds are earliest struck. When the comparatively

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* "The Mexican Oil-Fields," by Dr Day, *Petroleum Review*, 5th June 1909.

shallow well territory along the axis shows signs of exhaustion operations are extended towards the flanks of the anticline, but by that time the initial gas pressure, which has played such an important part in expelling the oil from its source, has greatly diminished, and the contents of the oil strata are less rapidly given up. Had the flanks of the anticline been tested in the early stages of development equally satisfactory results would, in many cases, have been obtained as along the axis.

The migration of petroleum is a subject very imperfectly understood. Gravitation will not explain the concentration of oil in some anticlines, and the great abundance of water in some of the most prolific anticlines proves that displacement is not the only active force. Water has doubtless been the transporting agent in many cases, but at what period and under what circumstances the migration of the petroleum occurred it is difficult to surmise.

In many cases the highly productive character of anticlines is probably due to the fractured and dislocated nature of the beds near the flexure, which has allowed porous strata to become charged with petroleum where elsewhere at less inflected and dislocated points the same beds are unpetroliferous.

It has been generally thought that petroleum accumulates in great subterranean caverns, and it is not uncommon to find in old works illustrations showing these imaginary reservoirs of oil which it has been the aim of prospectors to tap. That earth fissures do play some part in the distribution of petroleum as they do in the case of water cannot be denied, but the natural porosity of sedimentary strata is quite sufficient to account for the greatest accumulations of petroleum yet met with. Instructive investigations have been made to ascertain the porosity of certain classes of formation, chiefly for the purpose of water supply, and it has been shown that the most compact sands are capable of absorbing 10 per cent. of their bulk of water, whilst many sands have an absorption capacity equal to 25 per cent. of their bulk.

Subterranean Movements of Petroleum. — That there are constant subterranean movements of oil and gas still proceeding is intimated by the constant escape of oil and gas from outcropping oil strata or fractured crests of anticlines, and by the violent discharges of oil, gas, and mineral matter which occasionally occur along the axes of anticlines both on land and beneath the sea, when there are no apparent earth movements in progress. During earthquakes eruptions are frequent in oil districts, and in the region of Schemakha in the Caucasus, where earthquakes are frequent, it is said that gas and oil exude freely at such times from fissures which open in the earth. Generally, however, a comparative state of quiescence exists until wells are sunk and the general equilibrium of the fluid thereby upset in the exploited area.

The concentration of petroleum and gas in the anticlines must have been a long and gradual process which one only realises when considering the friction that has to be overcome in moving through miles of compact mineral substances, although, perhaps, at times aided by fissures. As soon as exploitation commences a general movement of oil occurs towards the points of abstraction, and, impelled by gas, the oil naturally follows paths of least resistance.

Pra tically all oil strata are severely faulted and cracked where the beds have been thrust into inclined positions such as Russia, Roumania, Galicia, Borneo, Burma, California, &c., and these planes of weakness probably influence considerably the distribution of the oil and productivity of the wells in some fields. Mr Ralph Arnold has called attention to the important part played by joint cracks in the California oil-fields, and records his views in the United States Geological Survey publication on the Santa Clara Valley, Puenta Hills, and Los Angeles Oil Districts, 1907. The faulting of the crest of anticlines is general where the beds are overturned (as in Fig. 5), or given a vertical throw on one side (Fig. 8).

In many cases wells sunk within the neighbourhood of a fault meet with such disturbed ground that they are

unproductive, besides often proving difficult to drill; but in certain cases the penetration of an inclined fault plane at a considerable depth may lead to the striking of an exceptional production. In the Bibi-Eibat field of Baku a number of important faults have been located, and they have been found to exercise a distinct influence on the production of the wells. A series of exceptionally large flowing wells were ascertained to lie along a fault which they struck at a considerable depth, and this information led engineers to locate wells to strike the fault at great depths. In one case the production of wells on one side of a fault was much greater than on the other, and this feature was distinctly traceable for a long distance across the field, which was actively exploited.

When the strata are too compact to be disturbed by gas pressure, the escape of gas and consequent reduction of pressure leads to a diminished production of petroleum, and a point is reached when the well can no longer be pumped at a profit. Deprived of gas, the flow in such compact strata is exceedingly slow, especially in the case of heavy viscous oils such as parts of California produce. A limited contamination with water is often the salvation of a field where such conditions pertain, and the productive life of wells is prolonged by the presence of salt water which mingles with the oil, rendering it more fluid, and flowing with it towards the points of abstraction. The following paragraph taken from the West Virginian Geological Survey of 1904, shows that the phenomenon described has not escaped the notice of other observers.

"When salt water is found in connection with the oil, as in the 'Hundred Foot' district of Butler County, Pa., or the Sistersville field in West Virginia and Ohio, most operators consider that a much greater proportion of the oil can be secured than where the salt water is absent, since the water acts as a rinsing fluid to flush the petroleum out of the sand and bring it freely into the well. It is also claimed by the practical oil producers that the tendency of the rock to

become clogged up with paraffin is much less when the petroleum is accompanied with salt water than when it is absent, so that for both of these reasons it is most probably true that the sand will yield up a greater proportion of its oil when the latter is accompanied by salt water."

In some oil-fields as much as 5 cubic feet of water are raised to each cubic foot of petroleum, and in many oil-fields equal volumes of oil and water are raised, and there is no doubt that in many cases its presence in limited quantities is beneficial.

In oil-fields where there is little or no water and the production of oil is small, the wells are carried 50 to 100 feet deeper than the oil source, so that a sump is formed into which the oil may percolate and be pumped intermittently according to the rate of accumulation. Intermittent pumping costs very little, and wells yielding one ton monthly are operated at a profit in Pennsylvania, West Virginia, and Canada by this system.

Expelled by gas at a high pressure, petroleum is generally ejected with considerable force when a virgin source is penetrated. If the containing stratum is a compact sand or hard vesicular limestone the oil may be discharged almost free from contamination with mineral matter, but if the force of expulsion is violent large masses of the containing or neighbouring strata may be thrown up or even plug the casing. Where the oil-bearing stratum is a loose, flowing sand a violent eruption will cause the dislocation and ejection of sand, and if the spouting continues for long thousands of tons of sand will be expelled. The removal of much sand, as always occurs, even when baling, in the Baku oil-fields, leads to the formation of an area of low density around the entrance of the tubing into which the oil infiltrates and accumulates prior to removal. For quite a distance around the well the sand may be impregnated to the extent of 50 per cent. of its bulk, thus forming valuable receivers for the supply to the wells. Where, as is not infrequent, many thousands of tons of sand have been

PLATE V.

FIG. 13.—SECTION OF OIL-BEARING STRATA ON ISLAND OF CHELEKEN, CASPIAN SEA.

Showing amongst other features the causes of irregular distribution of petroleum and variable depths and thicknesses of beds, and how fault planes may affect the production of wells. Similar features characterise most oil-fields where the beds are much inflected, and the reasons for widely differing logs of neighbouring wells is apparent.

[*To face page* 58.

expelled or raised with the oil, there is a considerable area of high absorption and low resistance, and into this area the exuding oil from all directions infiltrates, producing in time channels deviating in all directions which act as feeders. A favourably located well may, therefore, itself cause the conditions most conducive to the collection of oil, and so considerable is this influence that wells sunk at a later period in proximity to large producers fail to yield oil in payable quantities.

In loose strata, therefore, the wells themselves largely promote the concentration of petroleum, and time after time the author has had this peculiarity thrust upon his notice when sinking new wells in the vicinity of old producers in the Baku oil-fields, a new well failing to produce more than a fraction of the yield of an old well at the same depth as the old although in the same oil sand. One case illustrative of this feature occurred when the author opened up an old well after having been abandoned as unproductive for many years, with the result that for a while the well gave 40 tons daily where the best *new* well in that district would not have yielded more than 15 tons daily. Long standing had led to the slow infiltration of oil into the area of low density formed by the abstraction of much sand, and the same circumstance made its removal easy, whilst in the case of a new well in such a low-producing district there would not have been sufficient gas left to impel the oil into the well, and the exudation from the compact undisturbed bed would have been very slow indeed without the aid of gas.

A very little change of conditions often has a remarkable effect upon the subterranean movements of petroleum, as will be noted from the two following selected cases which came under the author's personal observation. A well, which had gradually *dried up* and eventually ceased to yield, was set aside for deepening, and a drilling rig was being erected when oil was found to be standing at a high level in the casing. In order to remove the oil, bailing was commenced, but the level

continued to be maintained, and it was found that a large production could be obtained. The deepening was abandoned, and the well continued to give for many years from 10 to 20 tons of oil daily. In another case the oil from a flowing well found admission to an abandoned well near by, down which it flowed in considerable quantities, with the surprising result that this old well commenced to flow with great vigour, and yielded immense quantities of petroleum. This was evidently due to the subterranean excitement set up by the introduction of great volumes of oil which opened up a new oil source in the vicinity previously excluded.

Violent spouters often play an important part in the subterranean circulation of petroleum. Where sand and masses of detached strata are ejected freely, the wells are alternately plugged and released, and the flow of oil and gas is intermittently checked and relieved, throwing thereby violent and momentary back pressures upon the strata. The instant liberation of the pressure following the fierce ejection of the obstructing masses causes intense inrushes of gas with further sand and detached fragments, which again choke the tubing and cause a recurrence. So violent and destructive is this intermittent action that the earth quivers for quite a distance around where a powerful gusher is in eruption, and the strata are fractured and dislocated over a wide area. Channels of low resistance are thus formed for the free movement of oil from long distances which would otherwise be non-existent, and it appears probable that the great producers of Baku owe their origin largely to the violence with which they originate.

The above contention is supported by the frequent introduction of oil to a well which violently ejects only gas, sand, and stones for a while—the oil sand and oil not originally present only appearing after a day or two when the ground has been greatly disturbed.

When the oil-bearing beds consist of hard compact sandstones or limestones a remunerative yield of petroleum is often only secured by blasting with powerful explosives, follow-

ing which shattering of the rock great productions are often obtained. Even after the lapse of years a second powerful charge of nitro-glycerine may be exploded with success and the supply of oil renewed.

The far-reaching subterranean disturbance occasioned in some classes of strata by the perforation of oil-bearing strata, where the gas pressure often exceeds 500 lbs. per square inch, is further illustrated by such instructive examples as the following, where the destructive action extended even to the surface of the ground. The pioneer well sunk in the Mamakai district of Grosny, Russia, flowed with such violence that all endeavours to effect its control were fruitless, for the oil and gas opened up passages in the earth around the well until the site partook more of the nature of a mud volcano than an oil well. Likewise, a well sunk to a depth of 2,860 feet by the Union Oil Company in Santa Barbara County in 1904 began to flow at a rate of 1,300 tons daily, ejecting at the same time much loose sand, but attempts to cap the well met with no success, as the oil commenced flowing from numerous cracks which opened in the ground for a radius of 50 feet around the well.* As recently as 1908 a deep well at San Geranimo, near Tampico, Mexico, sunk by the Mexican Petroleum Company, commenced to flow with such prodigious force that cracks were opened up in the earth for a radius of 250 feet, out of which oil and gas were expelled, producing a great crater, with an area of about 25 acres, which was eventually transformed into a lake of oil, into which the derrick and machinery sank. Most of the oil was consumed by a fire which broke out and burned for forty-eight days. It is estimated that some 2,000,000 tons of solid matter was ejected with the liquid.

Causes of Pressure.—Petroleum is often accompanied by so much gas, and occurs under such high pressure in new fields, that it is frequently ejected with terrific violence, defy-

* See "The Production of Petroleum in 1904," U.S. Geological Survey.

ing for a while all efforts undertaken to effect its control. Some of the fiercest ejections on record were met with in the early stages of development of the Baku oil-fields, when for weeks, and even months, 10,000 to 15,000 tons of oil were daily expelled from a single bore-hole, accompanied by an almost equal weight of sand and millions of cubic feet of gas. One noted well at Bibi-Eibat yielded, in 1892, 480,000 tons of oil in thirty days, and the first well drilled in Grosny gushed for years although all known means were tried to check the flow of oil. In Borneo the gas pressure encountered in some of the early wells has been so enormous that wells have been abandoned for a year or more until the gas pressure decreased sufficiently to allow the men to return and complete the well in the oil sands a little deeper. Often the discharge of gas in new territory is so great that the roar can be heard for many miles, and the air vibration is so great that it is painful to approach within a hundred feet of the well. In West Virginia closed gas pressures of 1,500 lbs. per square inch have been recorded, whilst 500 lbs. per square inch is a common pressure in many of the American gas-fields, where an output of 20,000,000 to 30,000,000 cubic feet of gas a day has been measured from wells not exceeding 6 inches diameter.

At one time the pressure was generally attributed to a hydrostatic head, and the estimations of pressure based on the levels of outcrops in parts of the United States gave some basis for such views, but the hydrostatic theory has now been discarded entirely as untenable. The pressures indicated by wells in the same locality bear little relation to one another, and there are at times such excessive pressures maintained for a while that hydrostatic origin is precluded from consideration. It is also found that many exhausted oil-fields do not become flooded with water as should be the case after the escape of gas and removal of petroleum by pumping if the gas and oil were impelled by water.

By some the high pressures have been ascribed to the

weight of strata overlying the oil-bearing strata, but this is scarcely worth serious consideration, as all rocks are capable of withstanding pressures far exceeding those due to the weight of the beds overhead, and the extraction of millions of tons of water and oil from subterranean sources causes no subsidence of land. It is now generally admitted that the pressures are entirely due to the accumulation of gaseous hydrocarbons, chiefly methane, which were formed with the liquid hydrocarbons, and exist in a highly compressed condition dissolved in the petroleum or accumulated in the beds immediately overlying the oil stratum. Petroleum is always accompanied by gas except where it exists in such positions that the gas has all been able to freely escape, in which case the petroleum rarely flows from a well, and never, unless left for a long time, rises to the surface unaided.

The widely differing pressures found in oil regions, where often 100 feet or less separates individual wells sunk into the same stratum, is due to many causes connected with the geological features of the beds. Faults and dislocations of strata may limit the area over which a single well draws its supplies, and so impede the free passage of the contained fluid that the pressure is small. In other cases local variation of texture may retard the admission of oil, or conversely the tapping of a slip plane in direct communication with the oil stratum may lead to the easy expulsion of great volumes of oil under high pressure.

Many of the high pressures met with in the early development of the Appalachian and Canadian oil-fields were evidently due to the concentration of gas in highly porous beds of dolomite, which freely evolved the fluid when an outlet was established. An ejection of 300 to 400 tons of oil, or a discharge of 20,000,000 to 30,000,000 cubic feet of gas daily, was usually not sustained for more than a few days, whilst in a few months or even weeks many of such wells became unproductive, or yielded but a nominal output, which, in the case of oil, could only be recovered by pumping.

Character of Oil-Bearing Strata.—The chief supplies of petroleum are always obtained from strata of a porous character, such as sands, sandstones, limestones, and fine gravels, although clays and shales are often petroliferous, and may yield small quantities of petroleum. The most productive oil-fields derive their supplies of petroleum from sands, which vary in composition from very fine grained to fine gravels, and in a well-defined petroleum zone any sands encountered are generally more or less productive of oil or gas.

The great producing wells of the Baku oil-fields and those of Borneo, California, Burma, Galicia, and Roumania are sunk in sands varying in quality from hard compact rock to loose flowing sands closely resembling quicksands. Some of the oil from the Eastern and Texan oil-fields of the United States and the Ontario oil-fields of Canada is obtained from limestones, but apart from these most of the oil of the world is drawn from sandy formations.

Sands and Sandstones.—Sands, which are generally shallow-water sediments, are naturally more erratically deposited than clays, marls, and limestones, which are essentially deep-water depositions, and less subjected to currents of variable intensity and direction, and in this fact is to be found a partial explanation of the somewhat erratic occurrence of petroleum. Where, as is occasionally the case, the oil-bearing strata are in proximity to seams of coal and lignite, false bedding and considerable lateral variation in the thickness of sands is frequent, such deposits indicating delta conditions or a proximity to land where variable currents would be expected.

The sands vary considerably in quality and thickness in the same field. At times there is a rapid succession of thin laminæ of sands and clay, whilst at other times a considerable thickness of clay separates beds of sands. Some sands are so fine that they are not readily distinguishable from clays, whilst others are as coarse as seashore sand or even fine gravels. The extremely fine sands are often only slightly productive of oil, but contain considerable volumes of gas

FIG. 14.—NODULE OF CALCAREOUS SANDSTONE WITH CARBONACEOUS NUCLEUS FROM BAKU OIL-FIELDS OF RUSSIA.

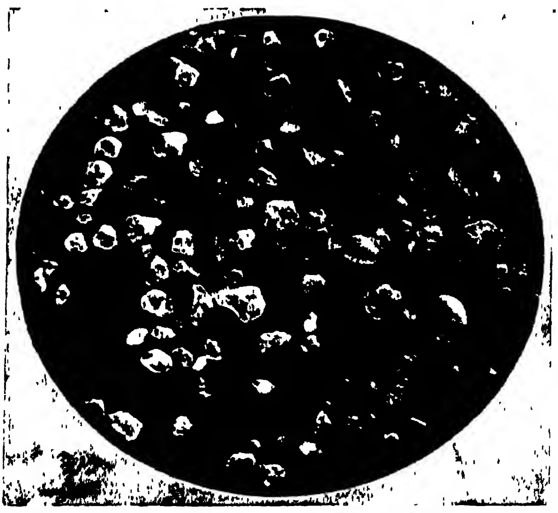

FIG. 15.—SAMPLE OF MOST PROLIFIC BAKU OIL SAND. (Enlarged 20 diameters.)

[*To face page* 64.

which is freely evolved when the beds are penetrated by the drill. The coarse sands are often full of oil and freely deliver up their contents when tapped, but in some fields these coarser varieties are heavily impregnated with salt water, and present considerable difficulties in passing and excluding the water when drilling a well. Owing to faulting or the lateral variation of sands, a trial bailing in a fine gas sand will often result in the ultimate admission of oil in large quantities, and the appearance of coarser sand from another sandy seam in the vicinity which did not extend to the well.

In many oil-fields the oil-bearing sands contain a large number of nodules varying in size from mere pebbles to spherical masses several feet in diameter, and where out-cropping sections are exposed to weathering, the harder nodules stand out in relief against the main stratum, which is more rapidly disintegrated. Some nodules are evidently concretionary, as they are found to contain an embedded fragment of partially petrified wood or exhibit a concentric structure, but in other cases evidence of stratification proves that such were not concretionary. Smooth, rounded nodules are, however, so common in sedimentary strata of all ages, that no special inference can be drawn from the occurrence beyond the fact that their production was frequent in the strata throughout which oil-producing conditions existed. Many tons of nodules varying in size from 1 inch to 12 inches in diameter have been raised from a single well in the Baku oil-fields, and these were often ejected in large numbers from flowing wells in that field. In the Roumanian, Californian, Burman, and Peruvian oil-fields nodules of calcareous sandstone are plentifully distributed throughout the oil-bearing strata. A curious kind of hollow concretionary nodule found in the Peruvian oil-fields is illustrated in Fig. 16.

The enormous quantities of sand ejected or raised with the oil in the Baku oil-fields causes an accumulation of the nodules in the sand around the base of the well towards which the fluid and sand flows, and when wells are deepened

or new wells are sunk near old producers many tons of collected nodules are often raised.

In some oil-fields where there is a large volume of gas, particles of detached sandstone which collect are often kept in such a constant state of agitation that the angular portions are knocked off and the fragments are gradually converted into nodules. Large quantities of such mechanically formed nodules have been collected from oil wells.

A peculiarity has in several fields been recorded in the lateral variation of an oil-bearing sand from intensely hard rock to a soft or loose flowing sand within a short distance, the difference being due to a cementation of the siliceous particles by lime in the harder variety and its apparent absence in the loose or softer portions. It is difficult to say whether the original stratum was all cemented with lime and subsequently removed by dissolution in patches, or whether lime was deposited at a later date, but in any case this feature is responsible for the periodical failure of wells sunk into oil horizons.

In a paper presented to the Petroleum Congress at Bucarest in 1907 * the author especially referred to this peculiarity of lateral variation within short distances in the sands of an oil horizon. In some parts of the Baku oil-fields, wells sunk into the hard calcareous sandstone, whilst never giving a phenomenal production, often yield a steady production for many years without the difficulties and dangers which always surround those sunk in loose sands. The oil in such cases is contaminated with very little sand, and it apparently exudes from fissures in the sandstone, as the rock itself is much too compact to allow of the passage through its pores of quantities reaching from 15 to 60 tons daily.

In the Peruvian oil-fields the author observed in an outcrop the variation from an oil-impregnated sand to an

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* "Notes on the Irregular Distribution of Petroleum," Third International Petroleum Congress, Bucarest, 1907.

PLATE VII.

FIG. 16. HOLLOW CONCRETIONARY NODULE FOUND IN PERUVIAN OIL-FIELDS.

FIG. 17.—IRON FRAGMENT WORN AND POLISHED TO SHARP EDGES EJECTED FROM MUD VOLCANO.

[*To face page* 66.

intensely hard calcareous sandstone containing no trace of oil within less than 300 feet, and the same peculiarity has been noted in some of the American oil-fields. Mr W. T. Griswold, in his Reports upon the Eastern Ohio Oil-Fields to the U.S. Geological Survey in 1902, stated, "In many instances, within a distance of 600 feet from wells of large production from a good sand, other test wells have found the sand hard and closely cemented and incapable of holding fluids of any description."

Limestones.—The large supplies of high grade petroleum found in the States of Ohio and Indiana are drawn from the Trenton limestones, which cover a vast area in those States. The petroleum appears to be confined to those portions where an extreme porosity has been brought about by a process resulting in the formation of dolomite, a double carbonate of calcium and magnesium. Such dolomitised limestones are estimated to be able to contain about one-tenth of their bulk of oil, and would allow the rapid expulsion of the contents if much gas were present.

In the Canadian oil-fields of Ontario, where a high grade oil similar to that of Ohio is obtained, the oil-bearing limestone closely resembles that of Ohio, although the productions are usually smaller, averaging but a few barrels a month. A sample of the porous limestone in the author's collection (Fig. 18, Plate VIII.), taken from a Canadian well near Petrolia, has a darkened colour, and is perforated with holes of considerable size which would give the rock a far greater absorptive capacity than 10 per cent.

The main productive stratum of the Spindle Top field of Texas was likewise a dolomite, although containing a preponderance of calcium carbonate. Messrs Hayes and Kennedy, in their Report to the U.S. Geological Survey in 1903, gave the following information concerning the nature of the oil-yielding dolomite of this wonderful oil-pool. Pieces of the stratum expelled from wells during the gushing period showed that the dolomite contained numerous cavities as much as an inch

in diameter, and there was reason to believe that cavities measured in feet occurred also. The cavities were lined with a layer of crystalline calcite, the free ends extending into the open spaces. Although no definite determination could be made of the relative volume of the open spaces, it was considered that the rock must have been able to contain at least one-third of its volume of oil. Such an exceptional porosity accounts for the extremely prolific character of the pool and its rapid exhaustion, both of which points have been the source of considerable speculation. Limestones are often impregnated with solid bituminous substances without any trace of liquid hydrocarbons, and sometimes particles of high grade bitumen fill vesicular portions of such rocks and readily flow therefrom when subjected to heat.

Brief mention is made of such bituminous rocks on p. 115.

Attached are a few representative well sections from several oil-fields of importance, which indicate the character of the ground encountered in the different fields :—

Well, Neosho County, Kansas, U.S.A.

(Yield, 4 to 5 barrels of oil a day. 5-inch casing to 623 feet.)

	Depth in Feet.
Surface soil	0- 20
Brown gravel (fresh water)	20- 30
Hard grey limestone	30- 56
Sandstone	56- 61
Hard grey limestone	61- 65
Soft grey shale	65- 70
Hard grey limestone	70- 75
Soft grey sandstone	75- 80
Soft grey limestone	80-115
Soft grey shale (limy)	115-125
Soft grey limestone (water at 128 feet)	125-130
Hard grey limestone	130-142
Soft grey shale	142-320
Soft light grey limestone	320-335
Soft grey shale	335-370
Grey sandstone (salt water and gas; hole filled up 200 feet)	370-385
Soft grey shale	385-400
Soft grey limestone	400-420
Shale	420-428
Hard grey limestone	428-458
Soft grey shale (limy)	458-490
Hard grey limestone	490-513
Hard black shale (water 40 barrels per hour)	513-521
Hard grey limestone	521-528
Soft grey shale (limy)	528-715
Soft grey shale (sandy, top of sand show of oil)	715-720
Soft grey sandstone and shale	720-728
Sandstone (oil sand, 22-feet pay sand at bottom)	728-752

Well at Humble, Harris County, Texas, U.S.A.

(Gas at 215, 508, 645, 670, and 700 feet. Some oil and much gas between 790 and 950 feet. Pay oil between 951 and 990 feet. Yield, 100 barrels first 24 hours. Diameter of well, $11\frac{5}{8}$ inches to 310 feet, 6 inches to 950 feet.)

	Depth in Feet.
Soft grey sand	30- 40
Hard grey clay	40- 60
Hard bluish sand	60-215
Hard grey sand and clay	215-310
Hard blue sand and clay	310-400
Loam grey sand	400-470
Fine grey sand	470-495
Hard blue clay	495-508
Hard blue sand and clay	508-572
Hard blue clay	572-645
Hard blue sand and clay in layers	645-710
Hard blue shale	710-950
Mixed rock and sand (limy)	950-990

Typical Well, Spindle Top, Texas, U.S.A.

(Water flush drill.)

	Thickness in Feet.	Depth in Feet.
Yellow clay	20	0- 20
Quicksand	36	20- 56
Blue clay	134	56-190
Quicksand	105	190-295
Coarse gravel	20	295-315
Blue clay	10	315-325
Hard blue shale	4	325 329
Blue clay	51	329-380
Coarse gravel	17	380-397
Blue clay	13	397-410
Coarse gravel	18	410-428
Coarse sand *with gas*	37	428-465
Blue clay	15	465-480
Blue clay mixed with nodules	15	480-495
Quicksand	12	495-507
Blue clay	83	507-590
White limestone	10	590-600
Sulphur and oil sand	2	600-602
Blue sandstone	18	602-620
Hard white limestone	5	620-625
Blue clay	7	625-632
Soft sandstone	11	632-643
Hard limestone	1	643-644
Blue clay	8	644-652
Soft sandstone	5	652-657
Blue clay	23	657-680
Shell formation	37	680-717
White limestone	20	717-737
Grey clay	11	737-748
White limestone	1	748-749
Grey clay with shells	31	749-780
Shells	7	780-787
Blue clay	7	787-794
Grey clay	16	794-810
Shells	2	810-812
Oil sand	3	812-815
Blue clay	5	815-820
Hard limestone	4	820-824
Black sand	6	824-830
White limestone	2	830-832
Soft dark shale	13	832-845
Soft white limestone	7	845-852
Soft dark shale	13	852-865
Blue sand rock	5	865-870
Quicksand	12	870-882
White limestone	3	882-885
Sand *with show of oil*	12	885-897
Blue clay	10	897-907
Iron pyrites	2	907-909
Dark clay	3	909-912
Oil sand	18	912-930

Well in Salt Lake Oil-Field, Los Angeles, California, U.S.A.

(Cable tools.)

	Thickness in Feet.	Depth in Feet.
Clay	36	36
Sand and gravel	24	60
Heaving sand (first water cased off at 110 feet)	30	90
Clayey shale	70	160
Sandy shale	90	250
Sandy shale (with salt water)	12	262
Clayey shale (2 feet shell at 275 feet)	13	275
Clayey shale (no water)	85	360
Clayey shale (4 feet shell at 398 feet)	85	445
Sandy shale	41	486
Sticky sandy shale	19	505
Coarse gravel and sandy shale	21	526
Sandy shale (4 feet shell at 632 feet)	146	672
Clayey shale (4 feet shell at 701 feet)	29	701
Sandy shale (shell at 785 feet)	94	795
Sticky sandy shale (second water shut off)	5	800
Sandy shale (considerable water)	118	918
Sandy shale	64	982
Sandy shale (small streak of white sand with water)	40	1,022
Sandy shale (some clayey shale and sand)	29	1,051
Sandy shale (*with some oil at* 1,070 *and* 1,080 *feet*)	49	1,100
Shale (much gas and oil entering)	10	1,110
Sand and shale (much oil)	22	1,132
Shale (carrying oil)	40	1,172
Shale and oil sand (much oil and gas)	53	1,225
Broken shale (much oil)	5	1,230
Shale and oil sand (much oil)	20	1,250
Shale (gas increasing)	18	1,268
Shale and sandy shale (with oil)	28	1,296
Shale (much oil)	12	1,308
Pulverised shale (1,310 to 1,315 feet, light oil beneath)	11	1,319
Shale (with oil)	19	1,338
Grey shale (strong gas)	4	1,342
Shale	42	1,386
Sandy shale (gas flow heavy; well filled up 400 feet with mud, water, and oil)	5	1,410
Light-coloured shale (no mud, no oil)	88	1,498
Well filled with oil to 100 feet of surface	—	1,510
Well commenced flowing	—	1,524
Oil sand (big flow of oil)	43	1,541

Typical Well Section, Baku Oil-Fields of Russia.

(Russian pole tool system.)

	Thickness in Feet.	Depth in Feet.
Upper clay and sand	35	0- 35
Blue clay	28	35- 63
Sand and small stones	11	63- 74
Blue clay (36-inch casing to 88 feet)	122	74- 196
Blue clay with inclined stone	60	196- 256
Yellow clay	10	256- 266
Water sand with rock	14	266- 280
Grey clay	49	280- 329
Water sand with rock	21	329- 350
Grey sand	42	350- 392
Water sand (34-inch casing to 406 feet)	14	392- 406
Sandy clay	35	406- 441
Blue clay	29	441- 470
Blue sandy clay	14	470- 484
Sand and rock	23	484- 507
Clay with sandstone	11	507- 518
Clay and water sand	3	518- 521
Grey sand	52	521- 573
Sandstone (inclined)	9	573- 582
Sand	2	582- 584
Sandstone (inclined)	29	584- 613
Yellow clay	38	613- 651
Grey sand and rock	47	651- 665
Grey sand	47	665- 712
Water sand	8	712- 720
Water sand and rock	41	720- 761
Hard sandstone	10	761- 771
Blue clay (30-inch casing to 782 feet)	13	771- 784
Yellow clay	101	784- 885
Gas sand	50	885- 935
Grey water sand	10	935- 945
Water sand and rock	27	945- 972
Grey sandy clay	51	972-1,023
Water sand and grey sand	13	1,023-1,036
Grey gas sand (28-inch casing to 1,050 feet)	28	1,036-1,064
Oil sand	7	1,064-1,071
Water sand (26-inch casing to 1,085 feet)	51	1,071-1,122
Gas sand and blue clay	51	1,122-1,173
Dry gas sand with some oil sand	45	1,173-1,218
Oil sand	15	1,218-1,233
Blue sandy clay (oil)	11	1,233-1,244
Dry gas sand	6	1,244-1,250
Gas sand and oil sand	48	1,250-1,298

		Thickness in Feet.	Depth in Feet.
Blue clay (24-inch casing to 1,323 feet)		27	1,298-1,325
Water sand		22	1,337-1,359
Oil sand		14	1,359-1,373
Water sand		25	1,373-1,398
Sandy clay (gas)		51	1,398-1,449
Grey sand		37	1,449-1,486
Variegated clay		11	1,486-1,497
Grey sand		8	1,497-1,505
Water sand and rock		16	1,505-1,521
Water sand	420 feet of oil in well	7	1,521-1,528
Gas sand and blue clay		21	1,528-1,549
Gas sand and brown clay		16	1,549-1,565
Variegated clay (22-inch casing to 1,582 feet).		22	1,565-1,587
Blue clay		15	1,587-1,602
Variegated clay		29	1,602-1,631
Clayey oil sand		14	1,631-1,645
Sandy clay		92	1,645-1,737
Oil sand (20-inch casing to 1,757 feet)		25	1,737-1,762
Blue clay		23	1,762-1,785
Blue marly clay		8	1,785-1,793
Oil sand (18-inch casing)		27	—

Cemented between 34-inch and 24-inch casings and between 18-inch and 24-inch to exclude water. Production 100 to 150 tons daily.

Typical Well in the Grosny Oil-Field of Russia.

(American cable system or Russian pole tool.)

	Thickness in Feet.	Depth in Feet.
Surface sand	—	0- 10
Yellow clay	37	10- 47
Grey clay (24-inch pipe stopped at 50 feet)	314	47- 361
Limestone	3	361- 364
Grey clay	134	364- 498
Dolomite (so-called—a hard stone)	2	498- 500
Grey clay	2	500- 502
Grey clay and dolomite	10	502- 512
Grey clay	6	512- 518
Grey clay, dolomite stone, and water	12	518- 530
Grey gassy clay	4	530- 534
Brown clay and dolomite	14	534- 548
Brown clay	10	548- 558
Brown clay and dolomite	12	558- 570
Limestone	2	570- 572
Grey clay and dolomite	18	572- 590
Brown clay	4	590- 594
Grey gassy clay, with exhausted oil sand	3	594- 597

	Thickness in Feet.	Depth in Feet.
Clay, with oil sand	11	597- 608
Dark grey clay and oil sand	10	608- 618
Brown clay and stone	4	618- 622
Dark grey clay	12	622- 634
Brown clay and sand	14	634- 648
Grey clay	9	648- 657
Green sandy clay	12	657- 669
Grey clay and sand	11	669- 680
Brown clay	19	680- 699
Grey sandy clay (20-inch pipes stopped at 706 feet)	11	699- 710
Brown clay and sand	10	710- 720
Grey clay and sand	10	720- 730
Brown clay	14	730- 744
Grey clay	14	744- 758
Green sandy clay	8	758- 766
Green sandy clay, with calcite	5	766- 771
Oil sand	4	771- 775
Green sandy clay	13	775- 788
Grey clay and calcite	7	788- 795
Dark grey sandy clay	4	795- 799
Grey sand	9	799- 808
Dark grey oil sandy clay	5	808- 813
Brown clay and sand	31	813- 844
Grey clay and oil sand	16	844- 860
Brown sandy clay	3	860- 863
Clay and grey oil sand	11	863- 874
Brown sandy clay (16-inch pipes stopped at 885 feet)	27	874- 901
Grey clay and stone	3	901- 904
Grey clay and sand	7	904- 911
Brown clay	3	911- 914
Grey clay and stone	6	914- 920
Grey clay and oil sand	30	920- 950
Grey clay and stone	6	950- 956
Brown clay and sand	7	956- 963
Grey clay and sand	15	963- 978
Brown gassy clay	3	978- 981
Green clay and stone	3	981- 984
Brown clay	3	984- 987
Clay and oil sand	7	987- 994
Grey clay and sand	8	994-1,002
Brown clay	35	1,002-1,037
Grey clay	1	1,037-1,038
Grey clay and oil sandstone	21	1,038-1,059
Brown clay and sand	2	1,059-1,061
Brown clay	35	1,061-1,096

	Thickness in Feet.	Depth in Feet.
Brown clay and stone - - - - -	6	1,096-1,102
Brown clay - - - - - - - -	18	1,102-1,120
Brown clay and stone - - - - -	20	1,120-1,140
Grey gassy clay and sand - - -	18	1,140-1,158
Brown clay - - - - - - - -	28	1,158-1,186
Grey clay, with exhausted oil sand -	10	1,186-1,196
Grey gassy clay - - - - - -	12	1,196-1,208
Brown clay and oil - - - - - -	18	1,208-1,226
Brown clay and stone - - - - -	2	1,226-1,228
Brown clay and sand - - - - -	13	1,228-1,241
Brown clay and stone - - - - -	2	1,241-1,243
Dark grey clay and stone - - - - -	6	1,243-1,249
Dark grey clay - - - - - - -	6	1,249-1,255
Dark grey clay and oil sand - -	3	1,255-1,258
Brown clay and sand - - - - -	14	1,258-1,272
Grey gassy clay and exhausted oil sand -	6	1,272-1,278
Brown clay and sand - - - - -	5	1,278-1,283
Brown clay and sandstone - - -	10	1,283-1,293
Brown clay - - - - - - -	15	1,293-1,308
Brown clay and stone - - - - -	13	1,308-1,321
Yellow stone - - - - - - -	2	1,321-1,323
Brown clay and stone - - - - -	8	1,323-1,331
Brown clay and exhausted oil sand - -	12	1,331-1,343
Brown clay and sand (14-inch pipe stopped at 1,344 feet) - - - - - -	3	1,343-1,346
Grey clay and oil sand - - - - -	2	1,346-1,348
Oil sand - - - - - - - - -	25	1,348-1,373
Grey gassy clay and sand - - - -	1	1,373-1,374
Oil sand (not very productive) - - -	6	1,374-1,380
Brown clay and stone - - - - -	4	1,380-1,384
Oil sand - - - - - - - - -	15	1,384-1,399
Grey clay - - - - - - - - -	15	1,399-1,404
Brown clay - - - - - - - -	16	1,404-1,420
Brown clay and stone - - - - -	12	1,420-1,432
Grey clay and green sand and stone -	6	1,432-1,438
Brown clay - - - - - - - -	25	1,438-1,463
Grey sand and water - - - - -	27	1,463-1,490
Brown sandy clay - - - - - -	13	1,490-1,503
Dark grey clay and sand - - - - -	6	1,503-1,509
Brown clay and sand - - - - -	11	1,509-1,520
Brown clay and stone - - - - -	3	1,520-1,523
Brown clay and sand - - - - -	7	1,523-1,530
Dark grey clay and sand - - - - -	15	1,530-1,545
- - - - - - - -	11	1,545-1,556
Brown clay - - - - - - - -	5	1,556-1,561
Brown clay, sand, and stone (10-inch pipe stopped at 1,592 feet) - - - -	26	1,561-1,587

	Thickness in Feet.	Depth in Feet.
Brown clay	19	1,587-1,606
Green clay and sand	9	1,606-1,615
Grey gassy clay and oil sand	5	1,615-1,620
Oil sand (good production)	5	1,620-1,625
Brown clay	13	1,625-1,638
Brown clay and oil	12	1,638-1,650
Oil sand	53	1,650-1,703
Brown clay	37	1,703-1,740
Brown clay and stone	4	1,740-1,744
Oil sand	11	1,744-1,755
Grey clay and oil sand	45	1,755-1,800
Brown clay and oil	23	1,800-1,823
Brown clay and stone	25	1,823-1,848
Brown clay and sandstone	4	1,848-1,852
Brown clay and sand	12	1,852-1,864
Brown clay and oil	16	1,864-1,880
Brown clay, oil, and stone	9	1,880-1,889
Brown clay and oil sand	7	1,889-1,896
Brown clay and oil	34	1,896-1,930
Grey clay and stone	8	1,930-1,938
Grey clay and sand	4	1,938-1,942
Grey clay, green sand, and stone	3	1,942-1,945
Grey gassy clay and oil	14	1,945-1,959
Brown gassy clay and oil	5	1,959-1,964
Hard sandstone	5	1,964-1,969
Brown gassy clay	16	1,969-1,985
Brown gassy clay and oil sand	9	1,985-1,994
Brown gassy clay	5	1,994-1,999
Oil sand (big flow of oil; flowed for weeks unaided; depth of hole 2,037 feet, 8-inch pipes to 1,988 feet)	3	1,999-2,002

Typical Well in the Tustanowice Oil-Field of Galicia.

(Production about 380 tons daily.)

	Thickness in Feet.	Depth in Feet.
Clay (17-inch casing to 87 feet)	98	0- 98
Shale (15-inch casing to 98 feet)	33	98- 131
Clay (13½-inch casing to 182 feet)	460	131- 591
Shale (12-inch casing to 246 feet)	98	591- 689
Clay (10-inch casing to 774 feet; water shut out)	124	689- 813
Laminated clay and shale	399	813-1,212
Clay	63	1,212-1,275
Laminated clay and shale	52	1,275-1,327

	Thickness in Feet.	Depth in Feet.
Shale - - - - - - - -	102	1,327-1,429
Laminated clay and shale - - - -	81	1,429-1,510
Sandstone - - - - - - -	13	1,510-1,523
Laminated clay and shale - - -	67	1,523-1,590
Shale - - - - - - - -	110	1,590-1,700
Clay - - - - - - - -	7	1,700-1,707
Shale - - - - - - - -	25	1,707-1,732
Laminated shale and sandstone - -	73	1,732-1,805
Shale - - - - - -	171	1,805-1,976
Laminated clay and shale - -	42	1,976-2,018
Shale - - - - - - - -	44	2,018-2,092
Sandstone - - - - - -	8	2,062-2,070
Shale - - - - - - - -	6	2,070-2,076
Sandstone - - - - - - -	32	2,076-2,108
Laminated shale and sandstone - -	74	2,108-2,182
Clay - - - - - -	8	2,182-2,190
Shale - - - - - - - -	6	2,190-2,196
Laminated shale and sandstone (9-inch casing to 2,204 feet) - - - -	37	2,196-2,233
Shale - - - - - - - -	49	2,233-2,282
Clay - - - - - - - - -	10	2,282-2,262
Shale - - - - - - - -	33	2,292-2,325
Laminated shale and sandstone - -	96	2,325-2,421
Shale - - - - - - - -	70	2,421-2,491
Laminated clay and shale - - -	49	2,491-2,540
Laminated shale and sandstone -	85	2,540-2,625
Shale - - - - - - - -	78	2,625-2,703
Sandstone - - - - -	7	2,703-2,710
Shale - - - - - - - -	43	2,710-2,753
Sandstone - - - - - - -	7	2,753-2,760
Shale - - - - - - - -	50	2,760-2,810
Clay - - - - - - - - -	4	2,810-2,814
Shale - - - - - - -	37	2,814-2,851
Sand with gas - - - - - - -	4	2,851-2,855
Shale - - - - - - -	65	2,855-2,920
Sand - - - - - - - -	12	2,920-2,932
Shale - - - - - - - -	68	2,932-3,000
Sandstone - - - - - - -	10	3,000-3,010
Shale - - - - - - - -	7	3,010-3,017
Sandstone - - - - - - -	25	3,017-3,042
Shale - - - - - - -	3	3,042-3,045
Sandstone - - - - - -	37	3,045-3,082
Clay - - - - - - - -	5	3,082-3,087
Sandstone - - - - - - -	13	3,087-3,100
Shale - - - - - - - -	23	3,100-3,123
Sandstone - - - - - - -	7	3,123-3,130
Clay (caving) - - - - -	32	3,130-3,162

	Thickness in Feet.	Depth in Feet.
Sandstone	21	3,162-3,183
Clay	17	3,183-3,200
Shale	61	3,200-3,261
Sandstone	7	3,261-3,268
Shale	62	3,268-3,330
Sandstone	7	3,330-3,337
Shale	42	3,337-3,379
Laminated clay and shale	41	3,379-3,420
Sandstone	40	3,420-3,460
Shale	62	3,460-3,522
Sand (oil at 3,540 feet)	38	3,522-3,560
Laminated shale and sand (caving ; $7\frac{5}{8}$-inch casing to 3,640 feet)	212	3,560-3,772
Shale	128	3,772-3,900
Laminated shale and sand (oil at 3,972 feet)	68	3,900-3,968
Shale	32	3,968-4,000
Laminated shale and sand ($6\frac{5}{16}$-inch casing to 4,150 feet)	160	4,000-4,160

Typical Wells in Negritos Oil-Fields of Peru.

(Casing perforated at various oil sources. Manila cable system of drilling.)

	Thickness in Feet.	Depth in Feet.
Grey shale (some oil at 220 feet)	770	0- 770
Oil sand (good oil source)	20	770- 790
Grey shale	55	790- 845
Oil sand (oil rose 600 feet in well)	35	845- 900
Grey shale	658	900-1,558
Oil sand (well flowing)	78	1,558-1,636

Grey shale	265	0- 265
Oil sand with oil	10	265- 275
Grey shale	275	275- 550
Oil sand with oil	20	550- 570
Grey shale	150	570- 720
Oil sand (well flowing)	25	720- 745

Initial productions, 20 to 30 tons daily.

Typical Canadian Well (Petrolia and Oil-springs District).

(Wire rope cable or Canadian tools.)

	Thickness in Feet.	Depth in Feet.		Thickness in Feet.	Depth in Feet.
Blue clay	70	0- 70	Lower soapstone	30	290-330
Upper limestone	50	70-120	Lower limestone (with oil)	100	330-430
Upper soapstone	150	120-270			
Middle limestone	20	270-290			

Deep Canadian Well to Trenton Limestone.

	Thickness in Feet.	Depth in Feet.
Clay	60	0- 60
Gravel	5	60 65
Black shales	85	65- 150
Limestone	15	150- 165
Soapstone	205	165- 370
Limestone	25	370- 395
Soapstone	25	395- 420
Corniferous limestone—black sulphurous water at 500 feet in Petrolia oil-bearing rock	115	420- 535
Dolomite, limestone, and marls, with gypsum and rock-salt. Red rock-salt, 1,410 to 1,655 feet; Red rock-salt, 1,810 to 1,835 feet	1,300	535-1,835
Limestone dolomite	225	1,835-2,060
Dark shales (Niagara)	15	2,060-2,075
Limestone (Clinton)	35	2,075-2,110
Red shales (Medina) and light grey shales with limestone	440	2,110-2,550
Shales (Hudson River)	285	2,550-2,835
Dark shales	175	2,835-3,010
Trenton limestone (only oil and gas bearing in places)	380	3,010-3,390

The thickness of oil sands bears a close relationship to the production of wells, and in fields where the lenticular character is pronounced there is often a considerable difference of yield between wells penetrating the thin and thick parts of the same sand. In some fields there is a succession of thin sands which collectively yield a remunerative production, whilst in other fields single oil-bearing sands attain a thickness of 20, 30, and even 100 feet and more. The greater the inclination of the beds, the greater is the depth of sand pierced by the drill, and

PLATE VIII.

FIG. 18.—TYPICAL OIL SANDS AND DOLOMITE.

1. Fine-grained, Richly Impregnated Oil Sand.
2. Rich Oil Sand from Outcrop. (The upper surface shows the bleached and disguised appearance as a result of prolonged exposure to atmospheric conditions.)
3. Oil-bearing Dolomitic Limestone. (Removed from a Canadian oil well.)
4. Coarse-grained Oil Sand Charged with Heavy Oil.

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the increased infiltration area thereby presented conduces to augmented yields, especially where the beds from which the oil is drawn are thin.

It is an accepted rule in practice to always drill completely through an oil sand before putting the well to pumping, in order to secure the benefit of the maximum infiltration area.

Area influenced by Productive Wells, and the Distance that should separate Individual Wells.—To ensure the most economical working of an oil-field, it is essential that the wells should be sufficiently separated to be unaffected by each other, and yet drain the field of oil as completely as is practicable, without leaving areas of undrained strata. This ideal end can never be achieved in practice, but it is the object of scientific operators to ascertain by trial the most economical distribution of wells over an area. Where the oil plots are of limited extent, and surrounded by active competing neighbours, it is usual to hastily drill a large number of wells along the boundaries of the property without any regard to economy, in order that the oil in that vicinity should be first obtained, as, naturally, under normal conditions where the oil is fairly equally distributed over an area, and a well draws from an equal radius in all directions, much oil must be drawn from neighbouring land.

Spirited rivalry between neighbouring producers always conduces to wasteful development, and in such fields as Spindle Top, Texas, Bushtenari in Roumania, Boryslav in Galicia, and the Baku oil-fields, where the land has been divided into small blocks, hundreds of thousands of pounds have been wasted in sinking dozens of wells in close proximity when the same quantity of oil could have been extracted from perhaps one-tenth of the number. The following pertinent paragraph appears in Mr Hayes' "Report on Texas Oil-Fields in 1903," when referring to the operations at Spindle Top:—"The conditions should have suggested to those concerned in the development, that a few wells properly distributed would have drained the pool as effectively as the

large number which have been drilled." In certain cases the drilling of more wells than actually required to drain an area is justified by temporary expedients such as high prices, or other local considerations, the quantity of petroleum that can be raised in a short time being greater from several wells than from one, although the total yield of the number may not far exceed the total amount that would have been yielded by one or two wells.

When the petroleum is highly charged with gas under considerable pressure, and the wells flow for a while without artificial aid, the depletion of a field is naturally more rapid under like conditions than when the oil has to be extracted by pumping or bailing, but generally the fields which display exceptional gushing properties are more prolific than those in which the wells only flow slightly, thus modifying comparisons. Some of the Baku wells drilled into new sources have yielded as much as 16,000 tons of oil a day for weeks, and in Texas and California some of the early wells gave as much as 8,000 tons daily.

In the 1904 United States' statistics mention is made of a well at Jennings Pool, Louisiana, which is described as the probable largest producer ever struck in America, having yielded 170,000 tons of petroleum in four months, an average of nearly 1,500 tons daily. Many of the early wells of the Campina district of Roumania yielded for a while 3,000 tons of oil daily, and from one famous well in the same field it is said that 14,000 tons of oil were ejected in thirty hours together with 150,000 tons of sand.* One well at Moreni, Roumania, gave 70,600 tons in two and a half years, and was still yielding 70 tons daily; another in Campina gave 100,000 tons, and was still producing 50 to 60 tons daily; and a well at Baicoi gave 40,000 tons in fourteen months. Some of the early Borneo wells gave 10,000 tons of oil daily, and more recently still wells in Mexico have given nearly as much for a while,

* Well No. 65, "Steaua Romana" Company.

and in one case at least the estimated output of a well was 13,000 to 15,000 tons daily for two months.

In the Boryslav-Tustanowice oil-field of Galicia many of the deep wells have for a time yielded from 100 to 500 tons daily, and some wells have produced over 100,000 tons of petroleum. In 1906 it was estimated that the average total production of the Boryslav wells had not been less than 37,000 tons, and one well in 1907 gave 2,000 tons daily.

Where there are several distinct oil strata at different depths, and only one is pumped at a time, it is possible to place the wells nearer together than when there is only one source, as adjoining wells are sunk to different oil horizons. When the oil-bearing stratum is a fairly compact limestone, or a consolidated sandstone, the rate of inflow into a well, even when accompanied by much gas, is slow after the initial expulsion of the contents immediately around the well. Thus the wells of Ohio, Indiana, Pennsylvania, and West Virginia do not yield more than 2 to 6 tons a month after an initial higher yield, and in many of the Californian oil-fields, where all the oil has an asphaltic base, the output of wells yielding 20 to 30, and occasionally 500, tons daily falls often to from 1 to 3 tons daily after a year or two.

In the Ontario fields of Canada the yield per well after the first few weeks often does not exceed 3 tons monthly, and both there and in parts of West Virginia, where the oil is of excellent quality, the production from numerous wells has averaged even less than 2 tons monthly.

There is always an exciting uncertainty in the production of oil wells which acts as an almost irresistible incentive to prosecute work further even when no success has rewarded persistent efforts, as so many cases have been known of capitalists abandoning wells when they were on the eve of success. One great producing well in a new territory will often repay many times over the losses occasioned over years of fruitless drilling. In nearly all oil-fields exceptional wells are periodically struck which are welcome sources of revenue

to the lucky producer, but it is bad policy to work only in such expectation, and in search of such to neglect less prolific sources, as heavy losses may be sustained by persistent disregard of average productions, and in endeavours to strike great gushers at increased depths.

The area influenced by a productive well is often considerable. Repeatedly cases have occurred where one flowing well has ceased when a new well has commenced to flow several hundred feet away. Likewise the cessation of pumping in one well often leads to an improved yield from another well near by, and it is a common practice in some fields to pump certain wells for water alone, as a stoppage of pumping leads to the flooding of adjacent wells which continue to yield petroleum as long as the water is deflected. In the Baku fields, cement, inserted around the casings of wells to exclude upper water, has been bailed from wells many feet away, showing the direct subterranean connection between the admitted water and the oil sources.

In oil-fields where the areas are generally developed in blocks of hundreds of acres, and there is no fear from active neighbours, one well is drilled to from 1 to 5 acres. Where wells are liable to collapse or damage from landslides the number of wells over a unit of area should be considerably increased to allow for those which are certain to be thrown out of development, either temporarily or permanently, at no distant date. In some of the American oil-fields, as at Spindle Top, Texas; Los Angeles, California; and other regions to which "rushes" have taken place, the lands have become so divided up into small blocks that the wells are huddled together, and the land exhausted or flooded by incautious development in a few years. In the Baku oil-fields where there are often from five to six wells on a single acre of ground there are excuses for overcrowding, as in parts of the field the area of individual properties does not exceed 2 to 3 acres, and in this there are certain restrictions concerning the distance of wells from the boundaries, and also from

FIG. 19.—GREAT FLOWING OIL WELL IN BAKU OIL-FIELDS.
Showing streams of oil and mountain of sand discharged almost burying the derrick.

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boiler-houses and dwellings if these latter exist. If such a small plot is surrounded by active operators a reasonable proportion of the oil underlying the ground can only be secured by quickly sinking a number of wells to the various oil horizons.

A rough calculation with extreme assumed factors will enable one to form an approximate estimate of the area that must be affected by the extraction of oil from a well. Roughly speaking, each one ton of oil is equal to a volume of 42 cubic feet, and if the bed be presumed to have a capacity of one-tenth of its bulk, an output of 1,000 tons would be equivalent to the exhaustion of $42{,}000 \times 10 = 420{,}000$ cubic feet of stratum. If the thickness of the prolific stratum were 20 feet, the area drained by the abstraction of 1,000 tons would be 21,000 square feet, or rather less than half an acre. Even if the extent of saturation is doubled in the case of Baku to 20 per cent. of oil by bulk we reach incomprehensible figures when the great producers of that field are considered. The ejection of 16,000 tons would be equivalent to the exhaustion of 3,360,000 cubic feet, and in a bed 20 feet thick this would represent an area of about 3¾ acres, and this daily rate of extraction has been continued without cessation in some cases for weeks. Some Baku wells have yielded as much as 500,000 tons of petroleum where it is possible that more than a single source was being drained, but if the thickness of the prolific sands affected was 100 feet, and the saturation as before 20 per cent., the area drained would be about 23 acres, whilst the affected area would probably have been double. In the above calculations no consideration has been taken of millions of cubic feet of evolved gases and the ejection of thousands of tons of sand. In one case the author estimated a yield of 10,000 tons of oil and 10,000 tons of sand daily from a single Bibi-Eibat well.

Production and Life of Oil-Fields.—Exhaustion, in oil-field phraseology, is a relative term only, and implies that

the oil-beds have been so far depleted that petroleum can no longer be extracted at a profit. An increased value or an improved system of drilling or pumping often attracts renewed activity to abandoned areas, and leads to the recovery of thousands of tons of oil from so-called exhausted areas, much in the same way as modern chemical methods enable abandoned mines or rejected "dumps" to be operated afresh at a profit. In most of the important oil-fields the supplies of petroleum are derived not from one single stratum but a succession of oil-bearing beds separated by unproductive strata, and in not a few cases the lower productive seams cannot be reached, except, perhaps, over a small area, with the appliances now in use, at a cost which justifies operations.

When once the high initial pressure of gas has been reduced by escape from numerous wells located over a definite area, the influx of petroleum into the wells is slow, especially when the density of the oil exceeds .900, but the wells continue to yield a small quantity of oil for many years if the sources do not become flooded with water. Many of the most promising oil-fields of the United States have been rendered valueless by water admitted to the oil stratum either during the drilling of numerous wells or by subterranean disturbances following the abstraction of large supplies of petroleum. Water-bearing sands are frequently found overlying oil-bearing beds, sometimes separated from them by only a few feet of impervious material, so that unless the greatest care is exercised, water will find admission to the oil sands around the casings of wells.

The above circumstances not only affect the life of individual wells but also the productive life of an oil-field, so that more than an approximate estimation of the life of wells or districts is impossible as it is dependent upon local factors. It is quite obvious that both the life of wells and of a field depends also upon the extent of drilling, but much also depends upon the gas pressure which expels the oil and the porosity, thickness, and number of oil-bearing strata. In some fields

a year to eighteen months will be occupied in sinking a well to the oil strata, whilst in other fields four to six weeks is the average time to complete a well.

The State geologist of West Virginia mentions in his 1904 Memoirs two wells which have been pumped for forty-three years and still produce from one to two barrels of petroleum daily, and there are many other wells reported to have been pumped for thirty years in the Appalachian oil-fields. In the Baku oil-fields there are wells which have continued to yield a remunerative production for twelve to twenty years, and which have given in that period from 1,000,000 to 2,000,000 tons of oil, and in Peru there are wells which have been pumped without intermission for fifteen years and given at least 5,000 tons of petroleum. In 1895 the average production per well in the Baku oil-fields exceeded 10,000 tons a year, whilst in 1909 the average had fallen to 4,000 tons a year, and the decline continues, although the wells are sunk deeper and deeper to tap untouched sources, and were in 1909 over 60 per cent. deeper than in 1895.

The advisers to the United States Geological Survey computed the average daily production of American wells in 1907 to be approximately as follows:—Appalachian oil-fields, 1.73 barrels; California, 42.56 barrels; Lima-Indiana, 2.74 barrels; Colorado and Wyoming, 8.35 barrels; Mid-Continent, 8.81 barrels; Gulf, 19.35 barrels; Illinois, 8.37 barrels.* The average life of Appalachian wells was estimated at seven years, those of Texas four years, and those of California six years.

In some oil-fields the majority of wells are not abandoned through exhaustion of oil but from defects which develop in the casing as a consequence of oxidation of the metal, or movements of earth causing collapse, which results in the exclusion of the oil by a flood of overhead water, or the formation of an impervious plug.

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* See Dr Day's "Petroleum Resources of United States, 1909."

The immense volumes of petroleum which permeate loose sands in favourable positions is astounding. From Plot XIX. of 27 acres at Bibi-Eibat, Russia, owned by an English petroleum company, located near the apex of the conical structure which characterises that field, no less than 8,000,000 tons of petroleum have been obtained from less than sixty wells during twenty years, which works out to an average yield of about 130,000 tons per well, and an output of nearly 300,000 tons per acre. This constitutes the world's record for a single property of like area, and the plot can also boast of having tapped one of the greatest flowing wells on record, in 1898, when 480,000 tons of oil were ejected in thirty days, an average of 16,000 tons daily. In 1898 eleven wells yielded over 900,000 tons, an average of about 82,000 tons per well. The total oil extracted would fill a reservoir equal in area to the property (27 acres) to a depth of 270 feet, but it is certain that a large proportion of the oil was not originally present in the small area worked, but was drawn from a large distance round.

The productive capacity of an oil-field cannot be estimated from isolated examples of chosen plots, but averages must be taken over a considerable area. The Balakhany-Saboontchy-Romany district in the Baku oil-fields covers an approximate area of 2,560 acres, and up to the autumn of 1908 some 128,500,000 tons of oil have been obtained, or approximately 48,000 tons per acre, and the district was in 1909 still producing at the rate of about 5,500,000 tons a year. The oil already drawn from the field would fill a receptacle equal in area to the field 46 feet deep, and there are certainly many million tons still awaiting extraction. Large areas of the field are periodically abandoned when prices fall, but these are returned to and operated with renewed vigour on a rise ot prices, which enables these so-called exhausted areas to be operated at a profit. The increasing cost of labour and materials, and the difficulties of drilling and excluding water which pours into the partially exhausted oil sands from upper

unexcluded water sources, will drive operators from the field when millions of tons of petroleum remain unrecovered. The average total yield per well before abandonment or loss in the Baku oil-fields has probably been between 40,000 and 50,000 tons, but the profits have not been so great as such enormous yields would lead one to expect on account of the high average cost of wells, the excessive cost of extraction by the bailing system, and the low price of crude prevailing for long periods. Between the years 1898 and 1908 the prices of crude oil in Baku have fluctuated between 7s. and 47s. per ton.

It has been estimated by American State geologists that the best parts of Pennsylvania have yielded about 200 tons per acre, and the State geologist of West Virginia estimates the oil-beds of that State to be capable of yielding a maximum of 650 tons an acre,* both of which productions are insignificant when compared with such fields as those of Baku. In reviewing this subject in 1909,† it was estimated that the average yield in the Pennsylvanian oil-fields will not exceed 100 tons of oil per acre, and over the whole Appalachian fields the yield will not exceed 135 tons per acre. In Illinois, where the "pay" streaks average 25 feet in thickness, the oil-fields are estimated to be capable of producing an average of 1,000 tons per acre. The Canadian oil-fields have been computed to yield only 50 tons per acre. The famous Bushtenari field of Roumania has been estimated to yield a minimum production of 9,000 tons of oil per acre, although the actual yield may eventually prove to be nearer 18,000 tons per acre.‡

The renowned Spindle Top field of Texas, with an area of about 200 acres, yielded in four years, from January 1901, 4,650,000 tons of petroleum, or about 23,250 tons per acre,

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* "West Virginia Geological Survey," vol. i., 1904.

† See "Petroleum Resources of the United States, 1909," by Dr David Day.

‡ "L'Exploitation du Pétrole en Roumanie," by I. Tanasescu and V. Tacit.

after which it was so far exhausted or flooded that only ninety-five productive wells remained out of the 1,200 drilled, yielding collectively 800 tons daily.* The average production per well during the four years had been approximately 3,800 tons, and the total oil extracted in that period would fill a reservoir equal in area to the field to a depth of 22 feet. Subsequent development in a more cautious manner led to an increased output again, and in 1907 the production of Spindle Top was 226,000 tons.

From the foregoing it will be seen how difficult it is to estimate, even approximately, the life of oil-fields, as there are too many unknown factors of a fluctuating nature. Many of the most promising new oil-fields of America have been suddenly and completely flooded by water, and the areas had to be abandoned,† and there are always special features in each field which are brought to light with extended development. Producers should always allow liberal sums against exhaustion for the acquisition of new lands, for that the land will become commercially exhausted sooner or later is absolutely certain, and unless new territory is acquired and exploited as the old becomes exhausted the fate of such concerns is certain.

Whether petroleum is indigenous to the strata or has an adventitious origin, it can be positively affirmed that there is no appreciable reproduction of petroleum proceeding to replace that abstracted. The oil-bearing strata become exhausted, commercially speaking, as coal seams or mineral veins by the extraction of their contents, leaving porous beds which will in many cases become eventually charged with water.

Selection of Sites for Drilling.—Where there is the ideal structure of unbroken anticlinal fold with gently sloping sides,

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* See "The Production of Petroleum, 1904," by F. H. Oliphant, United States Survey.

† See p. 260.

the best site for pioneer wells is certainly as near to the crest as possible, but where, as is more usual, the anticline has unequal slopes often steeply inclined, the wells should be located somewhat away from the crest on the less inclined side. The reason for this will be understood on referring to Fig. 8, where it will be seen that wells located along the apparent crest of an *unbroken* anticlinal arch may either miss the petroliferous zone entirely or penetrate vertical unproductive beds which may continue in that position to great depths. Where the anticline exposes a broken crest, and the oil-bearing series outcrop at the surface, or are merely covered by a local series lying unconformably upon the inclined petroliferous beds, the location of wells is decided by the relative inclination of the beds on each side, and the position of the outcrops of petroliferous beds. If the dip exceeds 50 deg., wells should be fixed to penetrate outcropping petroliferous beds at a depth of 800 to 1,500 feet; but where the angle of dip is in the neighbourhood of 20 to 30 deg., a fair test can often be made by locating the well to strike the outcropping beds at 400 to 600 feet. No fixed rule can be made for the selection of drilling sites in new territory, as much depends upon the character of the strata, but the author has found the above positions to work out well in some fields, although where the strata are much broken up and fissured the above depths may have to be greatly exceeded to obtain large productions.

Before fixing the position of trial wells on an anticline with an unbroken arch a search should be made for any lateral irregularity in the uplifting, resulting in the formation of dome-shaped structures around which the beds dip in all directions, as these conditions often favour excessive concentration of petroleum.

A new field should be tested by a series of wells at right angles to the strike of the beds, so that beds of a different horizon are tested in each case. In no case should the non-success of a single well be considered conclusive evidence of

the unpetroliferous character of a district, as there are few oil-fields in the world where there is not a proportion of dry holes even amidst highly productive wells.

Oil-Field Waste.—In no commercial operations has there probably been greater waste of the resources of nature than in oil-field development, some idea of which will have been gleaned by perusal of the preceding chapters. In the early operations in new oil-fields, where, uncontrolled by legislation, the work is allowed to proceed without restrictions in a reckless manner, hundreds of thousands of tons of petroleum have often been lost through fires, evaporation, or dissipation amidst surface beds from which it can never be recovered. On many occasions oil-wells yielding 10,000 to 15,000 tons of oil daily have burned for weeks, whilst in other cases equally large volumes have flowed to waste over the surface of the ground or ran away to sea to be irrecoverable.

Similar waste has occurred in the development of natural gas fields where operators have been unprovided with means of controlling the output from wells yielding tens of millions of cubic feet of natural gas daily. More natural gas is daily wasted in some of the smaller American fields than would supply the whole of London, and in many towns located in the gas-producing territories it was for years the extravagant practice to leave great gas flares burning night and day in the streets. In the early part of 1909 it was estimated that 70,000,000 cubic feet of natural gas, equal in heating value to about 1,500 tons of crude oil, were being daily wasted in the Caddo oil-field of Louisiana, and wells in Ohio and Kansas were allowed to discharge to the atmosphere 25,000,000 cubic feet daily, equal to about 550 tons of crude.

Under normal bailing conditions some 20,000,000 to 30,000,000 cubic feet of gas would be a low estimate for the gas which is daily wasted in the Baku oil-fields, although the fuel consumption amounts to 20 and even 30 per cent. of the oil recovered, whilst often individual gushing wells in the newer oil districts and at Surakhany yield many million cubic

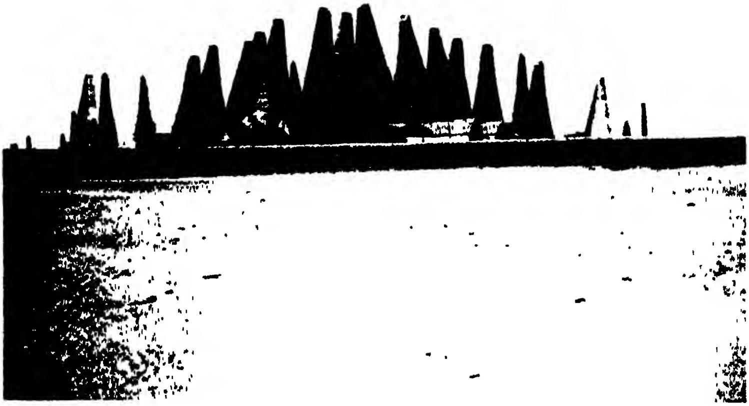

Fig. 20.—Group of Derricks in Baku Oil-Fields Protected with Sheet Iron.

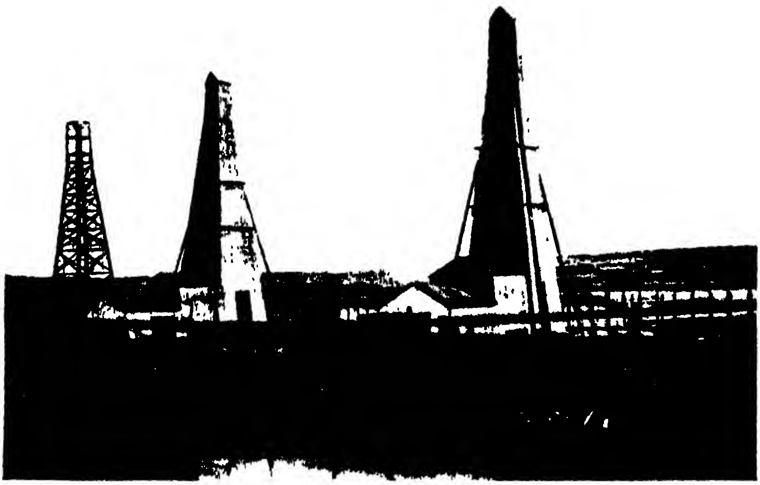

Fig. 21.—Derricks Protected by Uralite Non-inflammable Covering.

[*To face page* 90.

feet daily. In Roumania and Galicia the waste of natural gas is not much less than in Russia, and indeed in few oil-fields are effective measures taken to conserve or utilise the natural gas issuing from the wells.

The reckless waste of natural treasures is receiving yearly greater attention both from operators and public authorities and legislation is being introduced steadily to ensure greater safety and diminish losses. In oil-fields where wells are thickly grouped together and a structure must be constructed to house the machinery during drilling and subsequent bailing, the timber framework is frequently covered with some non-combustible material as sheet iron, asbestos, or some preparation as uralite, gypsolite, &c. Figs. 20 and 21 show derricks so protected, the wells in the former by sheet iron, those in the latter group by uralite. The protection lies chiefly in preventing the burning framework from being carried about in the vicinity by winds and in preventing sparks from a neighbouring conflagration reaching woodwork. Derricks so covered collapse into a heap after burning, simplifying the confinement of the conflagration. Oil chutes and settling tanks are now generally fitted with covers as a protection from floating sparks which might be conveyed from neighbouring fires, and water sprinklers are often fitted around dangerous structures.

Whilst fire has been responsible for astounding losses of oil, it probably represents but a small proportion of the total losses through evaporation and soakage. In the early period of most oil-fields steel or masonry storage is not introduced, and the produced oil is allowed to accumulate in natural depressions or earthen tanks hastily excavated. In some sandy strata the soakage is very great, but in some fine sandy materials or clay beds such storage results in little loss from percolation. Under any circumstances the evaporation resulting from the combined action of sun and wind often reaches a very high figure, especially in the case of the lighter oils. It is now becoming usual to erect large circular steel tanks or underground ferro-concrete tanks for the storage of petroleum,

and in hot climates the steel tanks are painted white and often protected from the direct rays of the sun by circular screens placed a foot or two away from the tank side.

From the drainage of the Baku oil-fields some 15,000 tons of oil are annually recovered by a contractor, who pays the authorities a substantial rental for the right.

Where great gushers are struck which cannot be controlled, the oil flows to depressions in the ground, where it collects and suffers great loss, but if exhausted oil-wells exist in the district the oil should be directed towards these and allowed to enter the exhausted sands. Experiments are being conducted in America to ascertain the feasibility of leading superfluous gas from early wells sunk in a new oil or gas field to exhausted areas, and charging the old beds anew with gas, and using them as reservoirs until the gas is required. The plan will probably succeed if measures are taken to properly seal or cement up all abandoned wells penetrating the strata to which the gas is led.

There is often great waste of the most valuable constituents of crude oil through inaccessibility of markets or the imposition of unreasonable freights and charges to points of consumption. For many years it was the practice in Russia to burn kerosene and benzine in the refinery as fuel in consequence of the demand for fuel oil so far exceeding that for the light products in the same markets, combined with the necessity of removing the light products from the crude oil for purposes of safety.

The greatest economy of oil can be effected by using petroleum and gas in internal combustion engines instead of burning beneath boilers or in other furnaces as is now usual. This end cannot be achieved for many years, as important improvements in internal combustion engines must be made before they compare in reliability with steam engines, and they are so simplified that they can be entrusted to unskilled labour of any kind met with in out-of-the-way places where oil-fields are often located.

CHAPTER III.

INDICATIONS OF PETROLEUM AND PHENOMENA ASSOCIATED WITH ITS OCCURRENCE.

Surface Indications of Petroleum—Evolution of Gas—Mud Volcanoes—Accumulations of Asphalt—Relationship of Salt to Petroleum—Association of Sulphur with Petroleum—Bituminous or Asphaltic Rock—Oil Shales—Native Bitumens—Detection of Oil-bearing Strata.

Surface Indications of Petroleum.—The physical characteristics of petroleum-bearing regions vary widely in different countries. Prevalence of petroleum not uncommonly exerts a marked influence upon the topography of a district as a consequence of its injurious influence upon vegetation, but this latter is influenced to a great extent by the geographical situation of the locality and the frequency and amount of rain or prevalence of long droughts. In rainless or nearly rainless tropical countries, the presence of petroleum and other injurious compounds which usually accompany oil, have a very pronounced effect, and are often a contributory cause of many square miles of barren waste. In tropical and semi-tropical countries where abundance of rain falls, especially in hilly districts where the water rapidly flows away, the vegetation is little affected by the prevalence of petroleum-permeated beds; but in districts where the rainfall is small, the vegetation is often of a stunted character if present at all. In many of the dense tropical jungles of Borneo and Sumatra in the East and of Central America and Trinidad in the West, where oil conditions prevail, the wild vegetation seems to flourish unchecked amidst a mass of bituminous matter and in quagmires of oily slime; even the famous pitch lake of Trinidad, although composed largely of solid asphalt, is not devoid of

vegetable growth, for dotted over its surface are tufts of coarse grass and low scrubby bushes, that maintain a bare existence on particles of soil attached to the pitch. Bare, barren wastes characterise the oil-fields in the almost rainless regions of Upper Burma, Persia, Egypt, Algiers, and Peru, as well as many of the Russian oil districts, and some of the western fields of the United States.

The presence of petroleum in the rocks of a district is not always indicated by any outward signs which would give the least clue to a casual observer. Many of the oil-fields of the world owe their discovery to the casual striking of oil in wells sunk for water, or during searches for brine which is commonly associated with oil. Drake's original well at Oil City was sunk amidst brine wells, and as recently as 1908 a rich find of oil resulted from the drilling of a water well in the Argentine Republic, at Commodora Rivadavia, by the Government of that country. In some regions there are seepages of crude oil which intimate the existence of supplies beneath the surface, and occasionally the issuing oil is allowed to accumulate in pools from which it is periodically removed. On two occasions, in the years 1908-1909, great quantities of petroleum suddenly issued from cracks in the ground along the Trans-Caucasian Railway, where oil-bearing strata occurred; and in the later case, near Aliat railway station, it was said that the oil flowed in such quantities that large lakes of oil were formed on the surface, inundating the railway line for some distance. The varied phenomena attending the distribution of petroleum will be described and explained in detail in the following pages.

Evolution of Gas.—Whilst natural inflammable gas is not by any means a positive indication of the existence of petroleum, its association with that mineral is so general in all parts of the world that it is impossible to disregard its presence if it occurs in a district where there is other confirmatory evidence, or the geological conditions are favourable. Not infrequently natural

FIG. 22.—VIEW IN PERUVIAN OIL FIELDS.
The Jerker line method of pumping over difficult ground is shown.

FIG. 23.—GENERAL VIEW OF BINAGADI DISTRICT OF RUSSIA NEAR BAKU FROM SUMMIT OF MUD VOLCANO.
Showing barren aspect of country and outcropping strata, also material ejected by mud volcano in foreground.

[*To face page* 94.

gas originates from causes quite different from those attending the formation of petroleum, whilst in other cases it accumulates in porous strata not directly communicating with oil beds, although it has been derived from them; but if there is a petroliferous or "paraffin" odour, the origin of the gas should be investigated and established before rejecting the idea of its association with petroleum. The escape of gas cannot be readily detected in dry, barren districts, but it is usually recognised by an odour pervading well-sheltered ravines, or by bubbles of gas rising from puddles of water or beds of streams. On applying a light to the escaping gas combustion takes place, and if the supply of gas is steady it will continue to burn with a slightly luminous, semi-transparent flame. In marshy ground, or stagnant pools, a similar escape of gas (methane or marsh gas) can often be observed, especially in warm weather if the mud is stirred, but this is merely a product of decomposing vegetation and quite distinct from that originating from petroleum. As is well known, the moving, feebly luminous flame of marsh gas sometimes occurring over treacherous marshy ground is commonly called the "Will o' the Wisp." Petroleum gas generally contains from 80 to 90 per cent. of methane, but there are other hydrocarbons present which impart to it a distinctive odour, and these simplify its recognition as petroleum gas.

Although petroleum gas can generally be distinguished by its odour, it is not infrequently contaminated to such an extent with other odorous gases that its qualities are masked. Both sulphur dioxide and sulphuretted hydrogen, as well as carbon dioxide and nitrogen, are commonly associated with petroleum gas, and the two former entirely disguise the petroleum odour at times. Small quantities of gas may continually escape through crevices and fault fissures from a considerable depth, and thus indicate the possible existence of an oil or gas stratum far below the surface; but usually the apparent gas exudations, often developed on a large scale, occur where there is a fractured crest of an anticline, or where

the strata lie at an angle, and the edges of the petroleum-bearing or gas-producing beds are either at the surface or are covered only by a comparatively thin layer of overburden. Usually the gas exudes slowly, but fairly constantly, from numerous points over a large area; at other times there are prolonged periods of quiescence between successive developments of activity. The gas only occasionally escapes with sufficient continuity and in large enough volume to burn incessantly if ignited, but at times such is the case, and gas exudations which have been accidentally lit or have fired spontaneously have continued to burn fiercely for years. On the ridge of hills fringing the Poota Valley, near Baku, there is an area of about an acre where the escaping gas is rarely, if ever, extinguished, and in the Yenangyat district of Burma there is a somewhat similar phenomenon at Yenang Daung. The gas appears to escape from numerous fissures in the strata, causing a large number of sheets of flame to rise to the height of a foot or two above the surface of the ground.

In the Surakhany district of the Baku oil-fields natural gas has been the object of worship for some 2,500 years, and it was only about 1898 that the pilgrimages to a temple in the district were suppressed by the Russian Government. Throughout the Surakhany area the gas has for many years been used by the peasants for burning limestone, which occurs locally, ample supplies being usually obtained by excavating 20 to 50 feet into the dark fine sands of that region.

In some petroleum regions the gas only bursts forth at distant intervals of time, the district in the intervening period exhibiting no indications of petroleum or gas. Such phenomena are frequent in the East and West Indian oil-fields, and in the Caucasian oil belts fringing the Baku oil-fields. In the Poota and Binagadi districts near Baku there are numbers of mounds which display violent activity occasionally. From one hill of more than ordinary fame, which, however, would not attract a casual observer's attention at ordinary times, the

gas occasionally bursts forth in immense volumes through numerous rents blown in the side, and the heat emitted by the burning gas, which ignites spontaneously, is intense. The glare is distinctly visible from Baku, 10 to 12 miles away, and the spectacle usually attracts a number of sightseers. The author was twice in Baku when this particular hill was in eruption, once in 1890 and again in 1904, but many years often elapse between successive eruptions. An examination of the hill after the few days' activity had ceased revealed unmistakable evidence of the intensity of the discharge, as cavities large enough to admit the body of a man were blown in the side of the hill, whilst the burnt nature of the material forming the hill testified to the great heat developed. In 1902 an eruption of gas, which also spontaneously ignited, caused the destruction of a herd of sheep grazing on the scrub in the Kir-Maku district to the west of Zabrat, Baku.

In some parts of the Caucasus the peasants utilise the natural gas for cooking and lighting by improvising stoves over crevices from which petroleum gas issues, when, to induce a large volume of gas to flow towards their stove, they often insert a short piece of piping into the crevice and make a clay puddle round the top of the tube to deflect the gas into the tubing.

Gas exudations are not confined to the land, they occur just as frequently in lakes, rivers, and seas. Some excellent examples of submarine exudations are found on the Caspian Sea and off the coasts of Burma and Borneo, where the oil-producing strata extend. It is said that at one time a light applied to the sea in Baku Bay, on a calm day, would result in acres of flame, but the active development of the Baku oil-fields has caused a diminution of such phenomena, although there are still several spots off Bibi-Eibat, near Baku, where the gas is evolved in sufficient volumes to cause the water to be violently agitated in the vicinity. A piece of lighted tow thrown into these patches will ignite the gas. In the presence of a stiff breeze the flame is blown aside and extinguished,

although on a calm day the gas continues to burn vigorously. Old inhabitants assert that gas escaped with such violence at one time near Baieloff that boats were capsized if incautiously allowed to approach too near. Near Holy Island in the Caspian there are similar exudations of gas from beneath the sea, they likewise resulting from the continuation of the oil-bearing beds seen on the island. There are many localities in the Caribbean Sea, off the coast of Mexico, where vast quantities of oil are periodically ejected, covering the sea for miles, and off the coast of Texas, near Sabine Pass, there are several well-known localities known as "oil ponds," where the sea is always calm, and where coasting vessels seek shelter during storms. These oil ponds are less than a mile in diameter, and the reason seas never break there is attributed to exudation of petroleum from submarine springs.*

The author has observed the escape of gas in the sea off the coast of Peru where there are well-defined oil-bearing beds on the shore, and sometimes the odour of petroleum gas is very pronounced in the breezes from the sea. Violent submarine eruptions have been reported off the coasts of Burma and the Klias Peninsula in Borneo, evidently attributable to the issue of petroleum gases following disturbance. Off Galeota Point, on the south-eastern corner of Trinidad, submarine eruptions have been recorded, accompanied by a great discharge of petroleum and pitch, which spread over the sea, and in the Gulf of Paria similar outbursts have caused a destruction of fish. The violent explosions, which were attributed to volcanic action, occasioned much consternation amongst the natives, who asserted that a great column of water rose from the sea to a considerable height at the moment of the explosion, and that the coast line for many miles was strewn with pitch and petroleum.

Other gases which are frequently to be found escaping

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* See "United States Geological Survey Report on Texas Oil-fields in 1903," by Hayes and Kennedy.

FIG. 24.—LARGE MUD VOLCANO IN DENSE JUNGLE.

FIG. 25.—TYPICAL MUD VOLCANOES OF ORDINARY DIMENSIONS.

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from the ground in oil regions are carbon dioxide, sulphur dioxide, and sulphuretted hydrogen. The carbon dioxide is not easy to discover, as it is an inodorous, non-inflammable, and invisible gas. Sulphur dioxide, easily detected by its pungent sulphurous odour and its stinging effect upon the nose, can often be traced in oil-bearing regions. It is prevalent in the districts around Baku where the oil strata approach the surface, and it has been observed in the Texan and Californian oil-fields. The gases accompanying the oil on Spindle Top, Texas, were exceedingly poisonous through association with sulphur gases, and many deaths resulted from inhalation. Sometimes the escape of sulphur dioxide from fissures leads to a sublimation of pure yellow sulphur around the crevices from which the gas issues, a result which is no doubt due to a chemical reaction between sulphur dioxide and sulphuretted hydrogen resulting in the production of water and deposition of sulphur.

Escaping sulphuretted hydrogen can often be detected in the vicinity of oil outcrops by its disagreeable odour, a property which renders its recognition easy. These poisonous gases, either singly or commingled, occasionally collect in natural depressions, where, undisturbed by winds, they form deadly pits in which wild animals or men are apt to be asphyxiated if they incautiously descend. Such treacherous places are known in the United States, Cuba, and elsewhere, the localities often being marked by a collection of bones of birds and animals which have unwarily ventured into these traps and met their doom. In the Caucasian oil-fields there are valleys where in the heat of summer and during the absence of a breeze the air becomes charged with these gases, producing a sensation of oppression and nausea if one lingers too long in them.

Many oil-wells yield an abundance of both sulphuretted hydrogen and sulphur dioxide; whilst sulphurous waters are a very common accompaniment to oil-fields. In Russia sulphurous waters abound around Baku, Grosny, Berekei,

Kaiakent, and Holy Island, and they also occur in Roumania, Galicia, Burma, East Indies, California, and, in fact, in nearly all oil regions of the globe. Some sulphurous springs of great size have been flowing incessantly for unknown ages, those of Kaiakent and Grosny being largely frequented by patients seeking relief for skin diseases and other ailments. It is interesting to note that the sulphur springs of Torres Vedras and Caldas do Rainha, Portugal, occur in districts where the rocks are distinctly bituminous. Natural flowing sulphurous waters are nearly always warm, and it seems more probable that they derive their high temperature from chemical action than from great terrestrial heat abstracted whilst traversing fissures at a depth.

In Russia a number of hot flowing sulphurous waters have been struck when drilling for oil both in Grosny and Berekei, and the Baku wells often exhibit great quantities of warm sulphurous water when the sources are approaching exhaustion. Quite a quantity of steam is emitted from such wells, where, prior to approaching exhaustion, no unusual temperature was recorded. Some of the sulphur waters met in the island of Cheleken in the Caspian are so hot that drilling has to be suspended.

Mud Volcanoes.—One of the most common phenomena associated with the presence of petroleum is the mud volcano. Mud volcanoes result from the evolution of natural gas through soft strata impregnated with water which has either been admitted into the surface alluvium or was present in the beds from which the gas is evolved. If oil or gas bearing beds are covered by clays or recent alluvium which is either insufficiently thick to restrain the gas pressure below or becomes fissured by earth movements or landslides, gas escapes, and if water is present a mud is brought to the surface and deposited around the point of issue. In course of time the constant ejection of mud and evaporation of the moisture leads to the formation of conical mounds, through

PLATE XIII.

FIG. 26.—LARGE MUD VOLCANO IN ERUPTION.

Many thousand tons of puddled clay were ejected in a few hours, accompanied by the evolution of hundreds of thousands of cubic feet of inflammable gas.

[To face page 100.

the centre of which a channel still remains for the passage of gas and mud. Continuous action in districts not frequented by heavy rains causes the growth of hills a hundred, and even several hundred, feet high which become landmarks in the district. Such mud volcanoes are to be seen on an exceptionally large scale in Russia around the Baku oil-fields, and in the Kuban district near the Black Sea, and in the Taman Peninsula, where great streams of mud may be observed flowing down their sides, and particularly in the Borneo and Sumatra oil-fields and the Arakan Islands off the coast of Burma. The larger hills are usually the result of the combined action of a number of smaller volcanoes, and the summits will generally be found to be dotted with a number of small craters, and rarely a large single crater, from whence the mud and gas escapes.

So common is the phenomenon to which the term mud volcano has been generally applied that there are few oil-fields in the world in the neighbourhood of which they are quite absent. Naturally, they are more prevalent where the oil beds closely approach the surface on an anticline or where steeply inclined outcrops of oil strata lie covered by damp alluvium, but they are often quite absent where oil beds lie at a great depth below the surface or where the surface stratum is of too compact a nature to form cones of mud.

In Trinidad mud volcanoes are to be seen on an unusually large and interesting scale in the southern section of the island, and some of the larger become extremely violent at intervals, and even cause damage. A house on the Colombia Estate at Cedros was rendered almost uninhabitable by an upheaval from a mud volcano near by, and at other spots where they occur acres of land have been thrown into disuse by ejections of mud and oil. In February 1906 the author was fortunate enough to witness the eruption of one of the largest and most famous of the Trinidad mud volcanoes near Cedros, and secured a number of interesting photographs. Several acres of ground were quite bare of vegetation, and strewn

with newly-ejected argillaceous mud mixed with occasional fragments of iron pyrites, flints, and pieces of lignite. All over this area inflammable gas was oozing up through numberless fissures with a hissing sound, and towards the centre was a crater of stiff pasty clay kept in agitation and puddled by the evolution of immense volumes of gas. This central crater had a diameter of about 60 to 80 feet, and the discharged mud was so soft around that close approach was unsafe. At intervals of a few minutes violent eruptions occurred, accompanied by the evolution of enormous volumes of gas, causing the ejection of many tons of clay to a height of 20 to 30 feet. Before each explosion the ground for a radius of 50 feet heaved and quivered, and the central portion rose slowly until it burst, causing the expulsion of masses of clay, the bulk of which fell back into the crater in great blocks.

Where water is present in large quantities mud volcanoes do not display the same violence, as the well-mixed mud is kept thin by constant agitation, allowing the gas to escape readily through the fluid mass at any point. In another case the author made an estimate of material ejected in less than one hour, and found the quantity to exceed 35,000 cubic yards spread over an area of several acres. Large cracks opened up in the ground for an area of many acres.

On 21st December 1897 the disturbance occasioned by an earthquake led to the formation of a great mud volcano beneath the sea off the southern point of the Klias Peninsula of Borneo, when sufficient argillaceous material was ejected to form a new island 750 feet long, 420 feet wide, and 20 feet above sea-level. The eruption occurred on the crest of a well-known anticline with steep sides, on which petroleum and gas exudations had frequently been observed in other localities where it crossed the land.

Some renowned mud volcanoes exist on the Arakan Islands off the coast of Burma, and they often display unusual activity when an earthquake disturbs the inclined oil and gas bearing strata which occur in that region.

PLATE XIV.

FIG. 27.—MUD VOLCANO AND ASPHALT DEPOSIT ON OUTSKIRTS OF BALAKHANY OIL-FIELD, RUSSIA.

[*To face page* 102.

Probably one of the greatest mud volcanoes on record was formed off the Burma coast on 15th December 1907 when sufficient material was ejected to form an island 1,200 feet long, 600 feet wide, and 20 feet above sea-level, upon which a landing was effected by the officers of a British marine survey ship shortly after the eruption, when the mud still indicated a temperature of 148 deg. Fahr. a few feet below the surface. The greatest mud volcanoes appear to occur where the oil strata are inclined at a steep angle, and especially where there is a deflection in the direction of the anticline, and consequently unusual fissuring.

Accumulation of Asphalt.—Around many of the known oil-fields there are extensive deposits of the oxidised products of petroleum. Wherever petroleum-bearing beds outcrop at the surface or are only covered by a superficial deposit of soil or alluvium, there is often a slow exudation or "seepage" of petroleum which, exposed to the action of the atmosphere, is deprived of its lighter products and converted into a solid or pasty mass of asphalt. The character of the residue which accumulates depends upon local conditions and upon the quality of the oil, as well as upon the topographical nature of the ground. In low-lying or flat regions the issuing petroleum is not readily washed away by rains, and under the influence of normal atmospheric conditions it slowly loses its more volatile products and becomes converted into a black solid or viscous covering.

In hot, dry regions, where vegetation is scarce, sandy particles of dust soon attach themselves to the sticky pitch and produce a solid material of limited commercial worth on account of the large percentage of extraneous matter that has to be artificially extracted before the pitch constitutes a valuable article of commerce. Where the oil oozes from outcrops on the side of hills, deposits of contaminated pitch will often be found in the surrounding low-lying districts, but in very hilly districts all traces may be removed by rains,

which carry everything into the neighbouring streams. When the less volatile constituents of petroleum accumulate in a forest or tropical jungle the pitch will always be found to contain a large quantity of carbonaceous matter, such as fragments of wood and leaves, which are preserved from decomposition. Insects, animals, and birds which stray into the more liquid pitch are often engulfed, and their remains are perfectly preserved for centuries by this natural embalming. Attention is directed by the U.S. Survey to the large number of well-preserved remains of extinct animals that are to be found in the "tar springs" of the Los Angeles district of California, the larger animals having apparently been lured into these deposits by smaller animals and birds already caught and unable to escape.* Likewise in Peru the author discovered some pitch deposits in which there was an abundance of bones of large animals that had evidently become bogged and their remains preserved.

It will generally be observed that the petroleum does not exude from the whole line of outcrops as one might have surmised, but escapes from a larger or smaller number of conical mounds which are distributed along the strike of the outcropping oil rock. Such a condition seems to be due to two causes; firstly, the solidified asphalt forms, after a time, a hard covering through which further oil cannot thrust its way without some exertion of force, thus leading to the escape of the oil from other points of weak resistance which continue to be so unless they become choked by some obstacle; secondly, there is a tendency towards the formation of definite channels by the escaping oil, which, after centuries of action, are not readily deflected into new directions where resistance is greater. Both actions bring about the formation of conical mounds of asphalt from the centre of which the petroleum either constantly or intermittently exudes from small craters and flows down the sides. The existence of

* Bulletin No. 809, U.S. Geological Survey, 1907.

such channels through which the oil flows by preference is supported by the common occurrence of fine sand with the oil, the conclusion being that this represents the particles of rock detached from the bed by the oil during its slow progress outwards.

In some parts of the Caucasus there are hills of asphalt many feet in height through which a heavy black asphaltic oil still exudes from numerous points in all directions. So soft are some of these that they will not sustain the weight of a man's body, notwithstanding the addition of a large percentage of siliceous matter which has attached itself to the pitch and rendered it harder. An outcrop of the Baku oil sands on the edge of the famous Balakhany district is indicated by a hill of asphalt mixed with mud and sand over a hundred feet high, and notwithstanding the active development of the district, indeed almost the exhaustion of that particular region, oil and gas with some mud still ooze up from numerous little cones. On one side of this hill, known as Bog-boga, the removal of surface sand has exposed a rich deposit of solid pitch (*kir*) which is largely extracted by the Tartar peasants for the manufacture of asphalt for roofing purposes. Part of the island of Cheleken in the Caspian Sea is a sodden mass of the less volatile constituents of petroleum, and on Holy Island also the removal of the surface soil exposes great deposits of pitch, the accumulated residuum of thousands of tons of petroleum which have been expelled from the oil rocks and subjected to atmospheric influence.

In Russia, California, Trinidad, Venezuela, Cuba, Mexico, Borneo, West Africa, and many other places extensive deposits of surface pitch have been worked to supply the ever-increasing demand for various qualities of this material for road making, electrical insulation, waterproofing, &c. &c. The renowned pitch lake of Trinidad has been the subject of wild speculation ever since it fell into the possession of the British, yet its origin is as obvious as the smaller deposits

of similar material in other parts of the world. A brief description of this well-known and often described lake may be of interest, especially as it has for many years been the chief source of asphalt for the world.

The lake, which takes the form of a rough circle, and has an approximate area of 127 acres, is situated about a mile inland from Brighton, where a pier has been erected to simplify the loading of steamers, and on which houses have been erected for accommodating the white staff. The surface of the lake is practically level except for a peculiar series of crevices which are folds resulting from slow movements of the main mass as pitch is extracted from the outskirts, but it is quite hard and impervious to water, and its surface has the peculiar fine wrinkled appearance that one always associates with drying pitch. The absorption of heat by the black pitch is excessive, and the radiated heat renders a survey of the lake most fatiguing.

Near the centre of the lake an area of about an acre has a dirty yellow sulphurous appearance, and bubbles of gas, emitting the offensive odour of sulphuretted hydrogen and readily igniting on application of a light, can be seen rising from numerous conical mounds beneath a film of salt sulphurous water. In this locality the pitch is quite soft and scarcely sustains the weight of a man though it is neither sticky nor dirty, and a piece can be extracted without soiling the hand and kneaded into any shape by gentle pressure, a considerable quantity of water being squeezed out by the operation. This spot is supposed to be one of the main, if not the sole source of supply to the lake, and as careful surveys have shown this point to be slightly higher than the rest of the lake this view seems justified, although there is reason to believe that the lake is no longer being fed to any appreciable extent. A light portable railway traverses the edge of the lake, where the pitch is extracted in large blocks by pickaxes and thrown into trucks, and it is surprising to observe how easily the pitch is broken up into blocks in

PLATE XV.

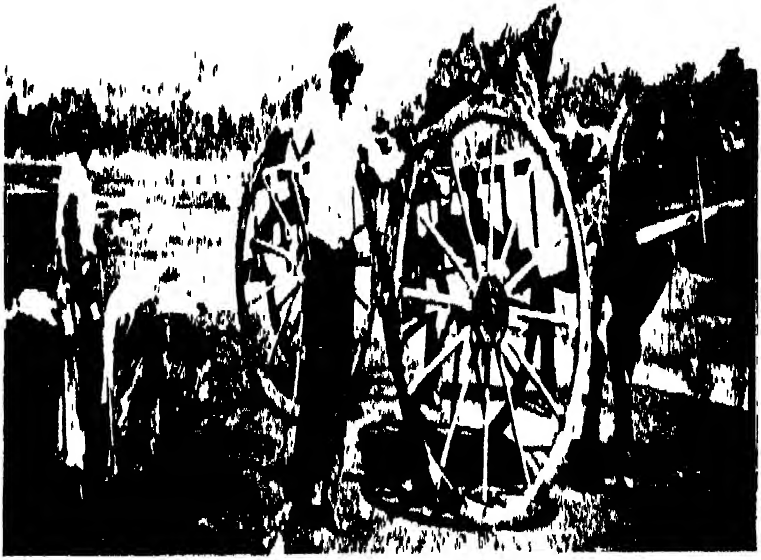

FIG. 28.—PITCH LAKE OF TRINIDAD.

Excavating pitch.

[To face page 106.

excavations about 2 feet deep, and it is still more astonishing on returning to one of these pits a few days later to find the original level reached again, leaving practically no trace of a depression.

The pitch exhibits a cellular structure, being full of gas holes, which assume an oval shape, and it contains 29 per cent. of emulsified water and about 25 per cent. of mineral matter, both of which can be largely removed by boiling, the water departing as steam and the sand settling to the base of the vessel. The whole contents of the lake are said by the manager to be in constant but slow motion which has frustrated all attempts to ascertain the depth of the pitch by means of bore-holes that became deflected, and the management relates how a 2-inch pipe sunk in a trial hole 135 feet deep disappeared, and reappears occasionally in far removed points of the lake to this day. The tube has become curved into a half circle and after showing itself for a short while it will disappear again only to protrude elsewhere at some subsequent date. This motion is also indicated by the appearance of trunks of trees with their roots complete during the course of excavation. The author saw one of these unearthed, and as pitch was found beneath the roots, to which much soil was attached, it was apparent that the whole had been carried bodily from the edges of the lake and had risen upwards with the pitch that filled the excavation after temporary abandonment.

Mr Clifford Richardson gives the composition of the pitch as follows, the sand consisting of fine siliceous particles with salts of minerals which have separated from the water, and some oxide of iron which transmits a red colour to the powder :—

Water and gas	29 per cent.
Organic matter	7 „
Mineral matter	25 „
Bitumen	39 „
	100 per cent.

The ultimate composition of the bitumen is :—

Carbon - - - - - - -	82.33 per cent.
Hydrogen - - - - - - -	10.69 „
Sulphur - - - - - - -	6.16 „
Nitrogen - - - - - - -	0.81 „
	99.99 per cent.

At one side of the lake is a depression in the rough basin occupied by the pitch, and through this has been traced the overflow of the pitch to the sea. The greater part of the distance is marked by numerous excavations where pitch at some time or other has been extracted or is being extracted still. The width of this overflow does not probably exceed 100 yards, but as the land has been in the hands of numberless private owners, who, unless bought out by the Asphalt Company, worked the pitch themselves, or leased it to others, the stretch has been the scene of considerable activity.

Nothing in Trinidad has been the object of more litigation, or the source of more revenue to the local lawyers, than this narrow strip of pitch-bearing land. The pitch, being fluid in character, naturally fills up a pit soon after it is emptied, the result being that the neighbours' lands are impoverished, and their ground level sinks or slips. Every person, therefore, has a complaint against his neighbour, and work is usually suspended by an order of Court pending a judgment. A Government Commission, sent from England to settle the points of law and formulate laws, made certain recommendations which were eventually modified and approved.

The old idea that the lake was inexhaustible is as fallacious as it was absurd, for already the level of the pitch has fallen 7.1 feet, and as 100,000 to 150,000 tons are annually exported, and over 1,500,000 tons have been extracted, it is obvious that its life will not be endless.

Recent geological work in Trinidad has conclusively established the origin of the pitch lake as the outcrop of a well-defined petroleum-bearing stratum, and the present pitch is nothing more than the accumulated unevaporated residue

of millions of tons of petroleum which have exuded for ages from these oil sands. The only difficulty that presents itself at all is the manner in which a sufficient depression was formed at an altitude of 138 feet above sea-level to contain that amount of pitch, an answer to which may be found in natural phenomena. The continued exudation of gas and oil naturally caused disintegration of the rock from which it issued, and as the angle at which the beds dip beneath the lake is known to be quite insignificant, the outcrop would occupy a considerable width, and much sand might be raised and be conveyed to the sea by the overflow. In course of time, after the formation of an extensive basin, either a diminution of activity, due to partial exhaustion of the gas, or to the pressure of a great mass of solidified pitch, would lead to a reduced discharge, and consequently a less active disintegration of the rock, which in turn resulted in a less contaminated quality of asphalt.

An example of such a naturally formed basin is to be seen in Trinidad to-day at Lagoon Boof, near Guayaguayare, where there is a great mud volcano about 100 yards in diameter, in which gas and salt water issue from a pool of mud which overflows on one side into a stream. The mud will not bear the weight of a man, and long poles pushed down fail to reach hard ground, even near the sides. A big basin of unknown depth has been formed on level ground at Lagoon Boof solely by the action of escaping gas upon the formation through which it issues; indeed, were this lake of mud on high ground, and were petroleum present with the gas, does it not seem likely that a lake similar to the pitch lake would be formed with an even distribution of mineral and organic matter?

Reefs of asphalt in the sea off La Brea bear testimony to the magnitude of the overflow from the lake, and the removal of millions of tons of earthy matter is quite reasonable when it is conjectured what volumes were dealt with. The oil-bearing character of the sands of the La Brea district is proved by petroleum issues in the surrounding jungle, and

more latterly by bore-holes sunk in the vicinity of the lake. Considering that the solid constituents of the petroleum, mixed with 29 per cent. of water alone, constitute the pitch in the asphalt lake, an idea can be formed of the amount of petroleum employed in its formation. Reckoning the quantity in sight and removed at 10,000,000 tons, or 3,900,000 tons of oil residuum (deducting the water and organic and mineral contamination), and that the pitch represents 10 per cent. of the original oil, we arrive at 39,000,000 tons of petroleum.

The Bermudez asphalt deposits of Venezuela, situated in the swamps at the mouth of the Orinoco, have long been worked both by American and English companies, but in that country the material is not emulsified, but consists of exudations of thick plastic bitumen which readily softens under the sun's heat. The asphalt, which is derived from petroliferous strata, occurs amidst coarse grass in swampy ground, and issues from numerous cones spread over an area of about 1,000 acres. Its viscous quality renders its extraction exceedingly difficult, especially as the thickness of the deposit nowhere exceeds 9 feet, and it is often covered by several feet of earthy matter. In the rainy season the area becomes so submerged that suspension of work is almost enforced, whilst in the dry seasons the coarse grass frequently becomes ignited, when the heat converts the upper portion of the asphalt into coke of no commercial worth. Mr Clifford Richardson gives the following information concerning Bermudez asphalt :—

ULTIMATE COMPOSITION OF BERMUDEZ ASPHALT.

Carbon	82.88 per cent.	Sulphur	5.87 per cent.
Hydrogen	10.79 „	Nitrogen	0.75 „

In its crude state it is mixed with 10 to 46 per cent. of water, but when dried it contains from 90 to 98.5 per cent. of bitumen soluble in carbon bisulphide, and 0.5 to 3.6 per cent. of mineral matter.

In Canada oxidised seepages of petroleum, which occur at

intervals in the Ontario fields, are locally known as "gum patches," and discs of solid bitumen thrown up by the sea along the coast of Texas are known as sea wax. These latter are sometimes 6 to 8 feet long and 1 to 2 inches thick, having a concentric structure, which suggests their formation from submarine seepages of heavy petroleum.

In many oil localities shallow pits sunk into the alluvium overlying the oil strata, or excavated in the productive seams themselves, will yield small supplies of heavy petroleum, which are often collected and utilised for the production of qualities of asphalt by further concentration. The extracted material is freed of water as much as possible by gravitation, and then heated in open pans until it reaches the desired consistency, after which it is run hot into barrels or tins and allowed to set.

Relationship of Salt to Petroleum.—Almost all waters contaminating oil formations are more or less saline, and it was the search for brine that led to the discovery of petroleum in the United States. For many years the Pennsylvanian salt makers had been much annoyed by the occasional appearance of oily matter which depreciated the value of their product, but it was not until Colonel Drake drilled his well in 1859 that the full value of the objectionable impurity was realised, and its abundance at greater depths demonstrated.

In Roumania thick deposits of rock salt are found amidst the oil beds of that country, and from these formations the Roumanian Government derives a considerable revenue by maintaining a salt monopoly. Rock salt is likewise found in the Galician oil-fields and ozokerite mines. In some countries where rain rarely falls the author has often observed that outcrops of rocks accompanying the petroleum series are coated with an efflorescence of salt upon their surface which entirely conceals the rock itself, and in rainless regions efflorescences of salt often cover the beds of valleys for many miles, their presence being due to the rising of salt water by capillary

attraction and the subsequent evaporation of the water at the surface.

In some petroleum districts salt plains or lakes are not uncommon. Wherever there are natural depressions without easy exit, and rain water can collect at intervals, salt is dissolved from outcropping oil beds, producing a solution of salt which in hot dry seasons suffers evaporation, leaving a white glistening deposit on the ground. The gentle evaporation under the influence of the sun and wind often causes the salt to separate out in beautiful rose-tinted crystals which form the loveliest of clusters. Dried salt lakes or salses formed in this manner are often the source of a large trade in salt, which when required for crude uses, such as preservation, needs no purification or preparation. The salt lakes of the Apsheron Peninsula surrounding the Baku oil-fields have for centuries been the centre of a salt trade with Persia and Asia; the salt lakes of America were a source of supply of salt to the Indians centuries before the whites were engaged in the business or oil was discovered in conjunction with the salt; and in China, Japan, and India salt was largely extracted from sources since proved to be petroliferous.

In most oil-fields the oil is raised mixed with salt water, and often the oil from flowing wells is intimately mingled with a proportion of salt water. The great Mexican gusher, which in 1908 yielded some 400,000 tons of oil in two months, eventually produced chiefly salt water at a temperature of 160 deg. Fahr., the flow being estimated at from 35,000,000 to 50,000,000 gallons daily.

So scarce is fresh water in the Russian oil-fields that the main sources for drinking are obtained from evaporators, whilst steam is universally generated from Caspian sea water. A characteristic sample of a Baku well water, analysed by Mr Beeby Thompson, gave the following analysis:—

	Grains per Gallon.
Total solids dried at 130 deg. Cent.	3269.50
Chlorine	1680.00
Nitric acid	0.90
Sulphuric acid	Trace
Carbonic acid	138.37
Iron	0.91
Calcium	5.88
Magnesium	17.53
Sodium	1155.85
Aluminium (+little iron)	12.81
Sodium chloride	2768.45 = 4 per cent.

The almost universal association of sodium chloride with petroleum must be acknowledged to be more than a coincidence, especially as the waters contaminating petroleum sources usually exhibit a degree of salinity far exceeding that of the oceans or waters impregnating deep-seated sedimentary rocks. In those oil-fields where deposits of rock salt have been distinguished interstratified with the oil-bearing formations the origin of the saline waters is obvious, but its occurrence is none the less instructive, as it conclusively indicates, if the oil is indigenous to the strata in which it is found, the geological conditions which existed about the period when the petroleum-forming organism or material was deposited. The well-known and industrially employed antiseptic property of common salt needs no mention, and one can scarcely evade the conclusion that it has been in some way instrumental in delaying or modifying the bacterial actions which resulted in the ultimate production of petroleum, although the nature of its action may long have to remain a subject for speculation.

Association of Sulphur with Petroleum.—Besides the exudations of sulphur dioxide and sulphuretted hydrogen already described, sulphur in some form of combination with the hydrocarbons composing petroleum is general; indeed, there are few crude petroleums which do not yield traces of sulphur when analysed carefully. Some petroleums are,

however, so impregnated with sulphur compounds that they give the crude a very disagreeable odour, and as they distil over with the pure hydrocarbons, most distillates have to be subjected to a special treatment to remove the sulphur before the refined oils can be sold. In some districts where the oil has been found to be specially impregnated with sulphur compounds, as in Texas and Louisiana, beds of crystalline sulphur have been penetrated in the oil-bearing series, and great thicknesses of limestones highly impregnated with sulphur have been passed through in search of oil.

In the Spindle Top district of Texas beds of crystallised sulphur were penetrated by many wells, and in the Calcasieu district of Louisiana a great sulphur-producing industry has grown up. The sulphur is extracted in the Calcasieu district by drilling wells into the sulphur-impregnated limestone, and forcing down between a 10-inch and 6-inch casing superheated water which passes through perforations in the outer casing, melting the sulphur, which runs to the base of the well, from which it is raised in a liquid condition by compressed air. By this ingenious process it is said that a single well will yield from 400 to 500 tons of pure sulphur a day, and as much as 60,000 tons of sulphur are said to have been so raised from a single well. Some of the limestones are reported to contain 70 per cent. of sulphur. Along the oil-bearing belt of Tertiary rocks in Peru there are several recorded localities where sandstones are heavily impregnated with sulphur.

In the Russian oil-fields the author has never found native sulphur except as sublimations from issuing gases, but iron pyrites is frequently raised from the wells, and it may be the decomposition of that mineral that has given rise to the presence of sulphurous gases, especially in partially exhausted oil sources.

There are few oil districts where sulphurous waters do not occur, and they often indicate an elevated temperature and are accompanied by natural gas. Two wells on plots 37 and

40 in the Grosny field of Russia, yielded each 150,000 gallons of sulphur water daily, at a temperature of 104 deg. Fahr. and 117 deg. Fahr. respectively.

Bituminous or Asphaltic Rocks.—In addition to the true oil-bearing strata, there are widely distributed over the earth arenaceous, calcareous, and argillaceous strata impregnated to a varying degree with bituminous or asphaltic matter. Some of the beds are permeated with a viscous, semi-fluid substance, whilst others are only discoloured and exhibit no obvious indications of their bituminous character until chemically examined. Many asphaltic rocks or tar sands are merely outcrops of oil-bearing strata where the evaporation of the lighter products of a petroleum which has already lost many of its lighter constituents has caused the concentration of the less volatile portions of the oil, or where the absence of the necessary geological conditions to produce and retain petroleum has led to the production of a dense intermediate product which saturates the bed and is retained in the pores of the stratum. In many cases the whole bed is stained and darkened with a bituminous substance in a solid state, although the fissures and cleavage planes sometimes contain thin films of solid or semi-fluid bituminous matter.

Bituminous sands and limestones are usually impregnated with 8 to 12 per cent. of bitumen, and where the latter occurs in a semi-fluid form with a low melting point its extraction is occasionally undertaken on a commercial scale by boiling water, steam, or direct heating in cupolas. The bitumen can also be extracted in a pure state by treating the rock with solvents, and this procedure is sometimes followed when a high grade bitumen permeates the beds.

The mining and treatment of bituminous sandstones has been extensively conducted in the United States, and especially in California where bituminous rocks abound, but few such enterprises have been successful, owing to the large deposits of the crude native material which can be worked at

a greatly reduced cost, and the cheap production of pure products from some low grade petroleum residuum.*

Bituminous clays and shales are very frequently found in all parts of the globe, but usually, whilst they yield a considerable volume of gas when heated, the liquid product rather partakes of the nature of a crude tar than an oil, and they are rarely treated on a commercial scale.

The European asphaltic limestones largely quarried in France, Switzerland, and elsewhere for paving purposes owe their usefulness to their purity, character of grain, and, to some extent, their regular impregnation with bitumen of suitable melting points and quality for withstanding extremes of temperature. Some of the asphaltic limestones in the United States contain as much as 25 per cent. of bitumen, but the irregular size of the grains diminishes their value for paving purposes.

The asphaltic sandstones, unlike the limestones, are almost invariably sands in which the grains are cemented together by bitumen, and when the bitumen is removed by solvents the rock crumbles down to a sand. The amount and quality of bitumen impregnating asphaltic sandstones varies greatly, whilst the rocks themselves range between fine sands to grits. Most of the great asphaltic sandstone deposits have resulted from original impregnation with petroleum, which has mostly escaped, leaving only oxidised heavy products impregnating and discolouring the strata.†

Burnt Bituminous Rocks.—Bituminous shales occasionally ignite spontaneously, and a slow combustion ensues for a long time, causing the shales to be burnt and converted into brick. Messrs Wall and Sawkins, when they made their

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* For full details of such operations, see the excellent publication of the United States Geological Survey, "Asphalt and Bituminous Deposits of the United States," by Eldridge.

† Full information concerning the composition and employment of asphaltic rocks for roadmaking is given in Clifford Richardson's "The Modern Asphalt Pavement."

extensive geological investigation of Trinidad in 1860, reported the occurrence of a burnt *red* shale in many parts of the island which they nominated porcelainite, as it was evidently a clay which had suffered considerable heat as a result of a slow combustion which had permeated the beds. Decomposition of sulphur compounds was probably responsible for spontaneous ignition, after which combustion continued slowly through the bed converting it into a red porcelain or brick of sufficient hardness to utilise for road construction on an extensive scale. The heat had obliterated all carbonaceous matter, but throughout the burnt shales are to be observed innumerable, well-preserved casts of leaves of plants with details beautifully delineated. Shales which have suffered such treatment are sufficiently hard to resist weathering and sea action much longer than the surrounding less durable rocks, and they have formed bold cliffs in many places round the south-western coasts of Trinidad.

A locality in Barbados known as Burnt Hill is evidently another example of the same action, slow combustion having converted a hill of bituminous shale into a hard brick-like rock, which has also been used for road construction.

Burnt shales have also been removed from wells in California at a considerable depth, thus showing that the process of combustion can spontaneously proceed without the assistance of air even at great depths. Eldridge and Arnold thus describe the burnt shales of the Santa Clara district of California: "The siliceous shale and 'chalk rock' forming the crest of the mountains south of the Santa Clara have at many points been burnt to a bright red colour. The fuel that supported such fires was perhaps the originally contained petroleum. Opposed to this view, however, is the very considerable depth to which the shale has been altered to a brilliant red lava-like rock, hence it may be inferred that spontaneous combustion alone has brought about the modification."

A somewhat similar phenomenon is not unknown in

England on the Yorkshire coast, where Liassic shales of a bituminous character yield a slight exudation of oil which occasionally ignites spontaneously, causing the surface of the cliffs to burn for a time.

Oil Shales.—Under the general designation of oil shales are to be found in many countries carbonaceous or bituminous shales which yield when subjected to heat hydrocarbons closely resembling those constituting native petroleum. Oil shales do not contain oil or substances soluble in oil solvents, and are composed of fine argillaceous matèrial through which is disseminated organic matter which often imparts to it a dark or even black tint and reduces its specific gravity. The petroleum is produced by the distillation of the shale, during which operation part of the embedded organic matter is volatilised and afterwards condensed, except such portion as forms a permanent gas, for subsequent distillation and refining when the constituent hydrocarbons suffer further changes. Good oil shales contain from 20 to 30 per cent. of volatile matter and will yield, on careful distillation in modern stills with steam, from 20 to 50 gallons of oil per ton, leaving as a residue shaly matter in no way resembling coke although it retains some fixed carbon. The extensive and remunerative treatment of oil shales in competition with natural oils has only been made possible by the high prices of paraffin wax and sulphate of ammonia, which latter is produced by using waste sulphuric acid from the oil refinery to combine with ammonia abstracted from the shale during distillation. Some shales, such as the famous Torbanite mineral, first treated for oil in Scotland, and the kerosene shales of New South Wales, partake more of the nature of a coal yielding 60 to 75 per cent. of volatile matter, and 6 to 16 per cent. of fixed carbon. Such shales yield from 80 to 120 gallons of oil per ton.

The Scottish oil shales, so largely worked in the West and Midlothian district by some six large companies, are

PLATE XVI.

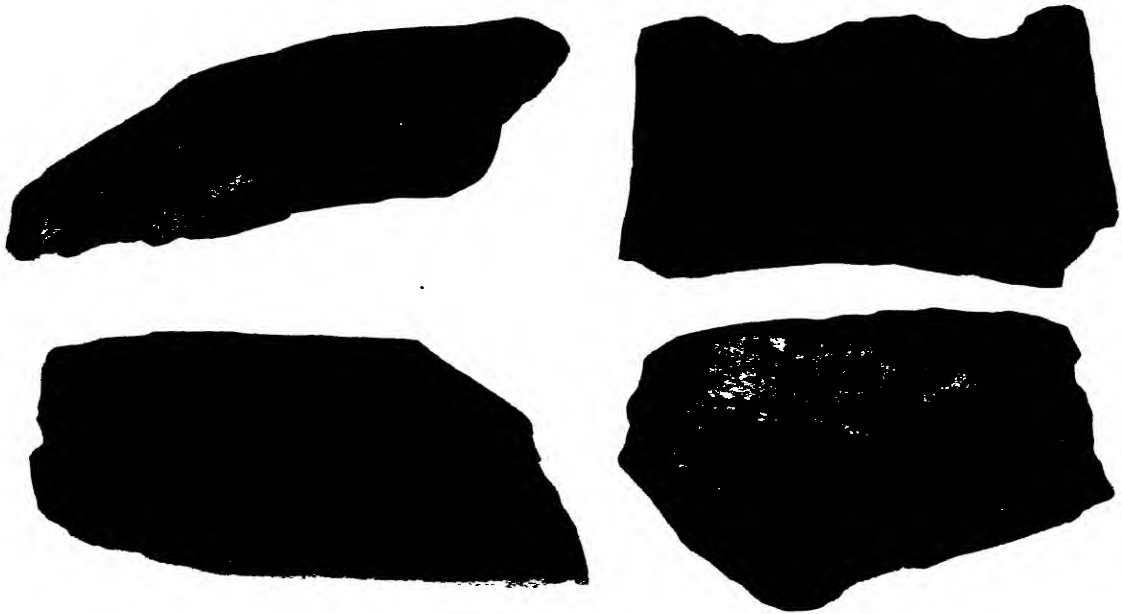

FIG. 29.—CHARACTERISTIC OIL SHALES.

1. Scotch Curly Shale.
2. Spanish Shale (Grenada).
3. New South Wales Shale.
4 Burnt Shale (deep red colour).

[To face page 118.

found in seams from 1 to 8 feet thick, lying in synclinal basins of the carboniferous system (calciferous sandstone series), and they yield when subjected to distillation from 20 to 40 gallons of oil, and the equivalent in ammonia water of 30 to 60 lbs. of sulphate of ammonia a ton. Shales which yield the most petroleum on distillation usually give the least yield of ammonia water, and *vice versâ;* but the nature of the product depends also upon the retort and temperature of distillation and the quantity of steam admitted to the retorts.

Where shales have come under the influence of intrusive volcanic rocks which have been thrust into their midst in a heated state a natural distillation has ensued, causing the shale to assume a "spent" or barren character, and the generated liquid and gaseous hydrocarbons have sometimes impregnated neighbouring beds and fissured ground. Under such circumstances considerable quantities of liquid petroleum and gas have sometimes accumulated both in the volcanic and sedimentary rocks, and been ejected with force when the vicinity was tapped by bore-holes or mines; and in some cases the fluid petroleum has been drawn into the pores of intrusive rocks as the heated mass cooled, and caused the formation of a partial vacuum in the pores of the rock.*

The shales vary considerably in quality throughout their thickness, and a fair average value can only be secured by making a series of analyses from each few inches of depth and averaging the results.

In the Geological Survey's publication, "The Oil Shales of the Lothians," the character of the Scotch oil shales is thus described:—

"Oil-bearing shale, as known in the Lothians, is a fine black or brownish clay-shale with certain special features which enable it to be easily distinguished in the field.

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* See Sir Archibald Geikie's "Text Book on Geology"; also Memoirs of Geological Survey, "The Oil Shales of the Lothians."

Among Scottish miners it is termed 'shale,' and the stratified rock described by geologists as 'carbonaceous shale' is distinguished as 'blaes,' from the bluish colour which it often assumes, especially when decomposed into clay. This distinction is a convenient one in several ways, and will be adopted in this Memoir.

"These two types are readily recognised in the field, but bituminous blaes may graduate into regular oil shale in such a way that it is impossible sometimes to draw the dividing line between them. Bituminous blaes if fairly rich in ammonia and volatile hydrocarbons may pass for shale if a practical test proves it to be workable for oil and ammonia on a profitable scale. As a general rule, good oil shale can be distinguished by its brown streak, toughness, and resistance to disintegration by the weather. Ordinary black blaes is more or less brittle and often gritty, and when exposed to the air it cracks and crumbles into fragments which ultimately revert to their original condition of clay or mud. Oil shale, on the other hand, resembles hard, dark wood or dry leather, and its quality in the field is measured by the degree of facility with which it can be cut and curled up with the edge of a sharp knife. It is free from grittiness, and is often flexible as well as tough. Some seams, such as those that crop out on the shore at Society, near Hopetoun House, instead of breaking up like blaes, form slabs sometimes a couple of feet in length, and are washed about and rounded the edges by the waves.

"Miners draw a distinction between 'plain' and 'curly' shale, the former variety being flat and smooth, and the latter contorted or 'curled' and polished or glossy on the squeezed faces. The same seam may be partly plain and partly curly, and curly beds are often richer in oil than the plain portions. Shale is probably curly because it is rich, as the higher percentage of hydrocarbon in some beds may have rendered them more easily crumpled than the stronger but poorer bands alongside of them.

"In internal structure oil shale is minutely laminated, which is apparent in the 'spent shale' after distillation, when it is thrown out in fragments composed of extremely thin sheets, like the leaves of a book or flakes in a piece of pastry.

"In thickness the shale seams vary greatly. At certain localities they disappear and pass into ordinary carbonaceous blaes, and at others they swell to 6, 10, or perhaps 15 feet in thickness, with subdivisions of barren blaes or ribs of hard calcareous or quartzose 'kingle.'"

Some oil shales from the province of Castellon, Spain, examined by the author's firm, showed a considerable variation in the yield of oil at different levels in a bed only 4 feet thick. Samples of shale showed 22 per cent. of volatile matter, of which 6 to 8 per cent. was water and 8 to 10 per cent. was non-condensible gas. A sample of the Castellon shale gave the following results on analysis:—

Crude oil - - - - - -			13.5 gallons per ton.		
Ammonia, equal to 9.2 lbs. of sulphate of ammonia per ton.					
Spirit - - -	sp. gr.	.790	5.3 gallons per ton.		
Lamp oil, first quality	„	.838	14.40	„	„
„ second quality	„	.864	14.90	„	„
Gas oil - - -	„	.906	16.22	„	„
Cleaning oil - -	„	.918	2.60	„	„
Lubricating oil -	„	.935	15.66	„	„
Scale - - - - - -			3.7	„	„
Total refined wax - - - -			4 per cent.		

Oil from one of the Broxburn seams of shale gave the following commercial products on treatment in the refinery:—

Crude oil (selling point, 89 deg. Fahr.)	sp. gr.	.872		
Naphtha spirit - - - - -	„	.740	1.36	per cent.
Burning oil - - - - - -	„	.810	31.60	„
Medium oil - - - - - -	„	.840	4.86	„
Lubricating oil - - - - -	„	.865	10.30	„
„ „ - - - - -	„	.885	10.08	„
Solid paraffin (melting point, 115 deg. Fahr.) -			10.52	„
Total products - - -			68.72	per cent.
Loss in refining - -			31.28	„

Native Bitumens.—Quite distinct from hardened oxidised surface seepages of petroleum, popularly known as pitch, asphalt, &c., which are always contaminated with earthy and organic substances, are certain high grade native bitumens of great purity which are the product of actions other than atmospheric on petroleum during its passage along subterranean fissures in which they are now found. The high grade native bitumens always appear as intrusions and fill fissures and fault lines in strata overlying oil-bearing strata; and their occurrence in a district may generally be regarded as an indication of the existence of oil-bearing beds in the vicinity, although they may possibly be unimportant or at too great a depth beneath the surface to be worked or even tested.

There are numerous qualities of such bitumens found in many parts of the world, their character depending upon the composition of the petroleum from which they were derived, and also upon the nature and rapidity of the absoiption or escape of the lighter products, which has probably been the main factor in their formation after the intrusion of the original fluid. The bituminous minerals vary from hard, brittle, glistening substances to softer dull masses which even possess a certain fluidity and will gradually flow from fissures into an excavation. With the exception of ozokerite, which is an almost pure paraffin wax and varies in colour from nearly white to black, all the native bitumens are black and generally have a bright and even brilliant lustre. Their commercial worth depends upon their melting point, insulating properties, elasticity, and freedom from impurities, and according to these qualities the minerals vary in value from two or three pounds to twenty pounds a ton.

Ozokerite, which is one of the most valuable of the native bitumens, is chiefly worked in Galicia, where the mineral fills fissures in much disturbed clays in the neighbourhood of the famous oil-bearing region of Boryslav. It evidently originates from a natural process of concentration whereby certain liquid hydrocarbons of paraffin-bearing oils are abstracted or escape,

Fig. 30.—Native Bitumens.

1. Galician Ozokerite (mineral wax). 2. Russian Bitumen (high value).
3. Californian Petroleum Residue. 4. Barbados Manjak (high value).

Samples 2 and 4 show the conchoidal fracture characteristic of the higher grade bitumens.

causing the accumulation of the residual solids in fissures and spaces of exceedingly disturbed strata into which petroleum had entered during subterranean disturbances. Ozokerite is found in small quantities in many districts besides Galicia, but nowhere in such large quantities, although immense unworked deposits exist on the island of Cheleken in the Caspian Sea.

Ozokerite has a specific gravity ranging from .850 to .950, whereas all other native bitumens have a density exceeding unity.

The common native bitumens mined in United States, Mexico, Barbados, Trinidad, Russia, New Brunswick, Syria, Nova Scotia, &c., have almost without exception a specific gravity exceeding unity, and they are known under a great variety of terms, such as Albertite (after Albert Mine, New Brunswick), Manjak, Grahamite (from Mr Graham, an operator), Impsonite (from Impson Valley, Indiana), Wurtzilite (after D. Wurtz), Gilsonite (after a Mr Gilson), Nigrite, Glance Pitch, and Elaterite.

One of the most common varieties is that to which Mr Clifford Richardson applies the exclusive term of Grahamite, and distinguishes as a pyro-bitumen in contradistinction to other minerals which exhibit different behaviour when treated with solvents. The main features which characterise Grahamites and render their recognition possible in the field are their brittle and dull nature, their frequent columnar structure, and the closeness of their melting points and temperatures of dissociation. The more valuable minerals, as Gilsonite and Manjak, melt and flow without decomposition at a moderate temperature, and when dissolved by solvents form products which, when applied to surfaces, are sufficiently elastic to prevent cracking under wide changes of temperature.

The veins of native bitumens have a width varying from an inch or less to several feet, and occasionally they open up into cavities many cubic feet in area. The edges of the mineral vein often partake of pencillated or columnar struc-

ture to a depth of several inches, and when the vein penetrates clays, the clays likewise to a depth of several inches are often characterised by a similar columnar form, evidently due to impregnation of material absorbed from the original bitumen-producing fluid. The veins often follow fault lines, whilst in other cases they penetrate fissures which deviate in all directions, rendering their development difficult. The original liquid character of native bitumens is proved by the occasional occurrence of pieces of unworn "country" rock embedded in the vein, as well as by the occasional penetration of liquid bitumen at points along the veins.

The author has observed that much gas is evolved during the mining of native bitumens, and masses are often ejected with violence from the working face by gas which has collected under pressure in the mineral. Professor Cadman has also proved that native bitumens absorb oxygen from the air very readily, and as much care should be exercised in ventilating bitumen mines and in adopting precautions against explosions as in collieries.*

The solid native bitumens are distinguishable from coal, which some closely resemble in appearance, by becoming viscous or fluid on the application of heat, and by their solubility in solvents, such as carbon bisulphide, chloroform, petroleum spirit, &c. Most native bitumens are also soluble in crude petroleum or heavy natural oil, sometimes called Maltha. The superior quality bitumens mined in Syria, Barbados, and Utah never occur in wide veins, and it is the less valuable materials known as Grahamites (Albertite and Wurtzilite) that are often discovered in veins many feet wide. On heating these latter they do not melt but intumesce, and the constituent hydrocarbons are dissociated with the production of gas, a residue of carbon resulting, if the heat is continued, but if heated with a proportion of heavy oil, in

* See paper read before Institute of Mining Engineers' Annual Meetings, 1908, by Professor Cadman, "The Mineral Resources of Trinidad."

FIG. 31.—NATIVE BITUMENS.

1. Trinidad Grahamite, showing pencillated or columnar structure.
2. Bitumen formed on Surface from Exudations of Petroleum.
3. Egyptian Bitumen (very valuable).
4. Utah Wurtzilite.

which they dissolve, disintegration is avoided and a homogeneous product is produced.

The ultimate composition of native bitumens is not far removed from that of heavy petroleums, but naturally the component hydrocarbons are chiefly unsaturated, and consequently the bitumens are readily attacked by sulphuric acid. The following table gives the ultimate composition of a few native bitumens taken from Eldridge's "Asphalt and Bituminous Rock Deposits of the United States," and Clifford Richardson's "Modern Asphalt Pavement."

TABLE XXVII.

Composition of Representative Native Bitumens.

Nature and Locality.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.
Wurtzilite, Utah - -	80.00	12.23	1.78	...	...
Gilsonite, Utah - - -	88.30	9.96	0.32		...
Albertite, Nova Scotia -	86.04	8.96	2.93	1.97	...
" " " -	85.53	13.20	0.42	...	1.20
Grahamite, West Virginia -	86.56	8.68	2.97		1.79
Egyptian glance pitch -	80.87	10.42	0.19	...	...
Trinidad Lake bitumen -	82.33	10.69	0.81	...	6.16

Detection of Oil-bearing Strata.—The attention of an oil prospector is generally directed to a new locality by some of the indications already described, but at other times no such obvious inference is to be drawn, and the initial interest is centred upon certain stratigraphical features resembling those in neighbouring regions where oil has been found, or where there are visible phenomena of a characteristic kind. The occurrence of sedimentary rocks of a certain age and of a composition and structure suitable for the accumulation of petroleum may first be the subject of comment, subsequent closer examination proving some of the beds to give evidence of contamination with bituminous compounds. Many sandstones, limestones, and conglomerates heavily charged with

bituminous compounds are so bleached and oxidised at their outcrops that they would attract no attention unless carefully sought, but when superficial layers are removed, they are often darkly discoloured with the heavier products of petroleum (Sec. 2, Fig. 18), and often emit a distinctive odour without the application of heat. The author has in some oil-fields been compelled to minutely examine strata which he felt convinced were oil-bearing before he could detect any manifestations of the petroliferous nature of the outcropping beds—a slight brown discoloration with a feeble ethereal odour when penetrated to a depth of a foot or two being often the only manifestation of petroleum on an outcropping stratum saturated at a depth with a light petroleum.

A curious phenomenon is reported by Mr G. E. Grimes in his geological report to the Indian Survey on the Yenangyat oil district of Burma, namely, that certain outcropping sandstone beds which show no signs of petroleum indicate a much higher temperature than the air and the surrounding strata, and these always prove to be oil-bearing at a depth.

Attention is often attracted to a bed by the occasional occurrence of a thin vein of black bitumen or grey ozokerite, which has originated from some petroleum in the region, or it may be an outcrop of a bituminous stratum; but many of the most productive parts of oil-fields have been struck in extensions of the originally selected sites, where the petroliferous series was entirely concealed by strata of a newer age, and where there were no surface indications to reveal the character of the beds beneath. Other oil-fields have been discovered as the result of geological surveys which have demonstrated the occurrence of suitably inflected strata of a geological age, and at a workable depth, that have proved productive of oil elsewhere in the same district.

CHAPTER IV.

ORIGIN, COMPOSITION, CHARACTERISTICS, AND TREATMENT OF PETROLEUM.

Origin of Petroleum and Natural Gas—Composition and Characteristics of Petroleum and Natural Gas—Uses of Petroleum Products—Distillation of Petroleum—Refining.

Origin of Petroleum and Natural Gas.—The problem of the origin of petroleum has been the subject of scientific controversy for many years, and few chemists or geologists of distinction have not been led into an expression of views at some time or other. The problem is still unsolved to the satisfaction of scientists, although the more active development of oil-fields and the increased scientific interest in petroleum has led to a much clearer perception of the changes resulting in the formation of liquid hydrocarbons. World-wide exploration has proved petroleum to be no curious fluid, produced, as was formerly thought, in a few isolated spots on the earth, where peculiar conditions existed, but a common, widely-distributed product of nature, which has been disseminated amidst sedimentary rocks of all kinds and ages.

In seeking the origin of petroleum, therefore, one must not introduce extraordinary theories for its production in certain localities, but must consider only such views which would account for its extensive production and wide distribution by common processes of nature. In certain exceptional cases bituminous compounds, which are closely allied to petroleum, may call for some unusual explanation, such as the occurrence of bitumen in meteoritic stones which have reached the earth, and the existence of similar products in volcanic rocks, but these isolated examples bear no intimate relationship to the

enormous accumulations of petroleum which it is the aim of the oil prospector to locate and develop.

Modern discoveries enable the chemist to produce many of the constituents of petroleum by reactions in the laboratory, and even to reproduce many of the extraordinary isometric forms of the hydrocarbons which predominate in crude petroleum. Many of the theories advocated or supported by leading scientists have been proved to be quite untenable, although no doubt ever existed that oil could be produced in the manner described, but geological considerations prevented the acceptance of these as natural methods of oil production.

There are two theories generally presented to account for the origin of petroleum, which may be described as the Inorganic and the Organic, of which latter both animal and vegetable theories of origin find advocates.

Inorganic Theories.—The inorganic theories attribute the origin of petroleum to chemical reactions in the interior of the earth, often involving the formation of gaseous hydrocarbons which rose in fissures from great depths and condensed and accumulated in upper cooler strata of a porous nature. This theory found many influential advocates at one time, and the ascertained action of water on the carbides of certain metals which results in the liberation of hydrocarbons was considered evidence in support. Many theories have been described which involved intricate chemical actions and peculiar terrestrial conditions of temperature and pressure, but they have never been generally accepted solely because much more simple and probable reactions will account for the occurrence of petroleum without introducing the many difficulties these theories make it necessary to admit.

In nearly all oil-fields the petroleum is confined to strata within certain vertical limits, which are underlain and covered by other unproductive sedimentary strata, frequently of a character quite suitable for the storage of petroleum. Had the hydrocarbons emanated from great depths, it is difficult

to understand why the lower beds were not impregnated, or why no evidence remains of the exuding fluids in the crevices and fissures themselves. In nearly all cases where there are veins of bituminous material disseminated throughout strata it is usual to find sedimentary beds impregnated with asphaltic matter beneath or in the vicinity of the impregnations, thus disclosing their origin.

The author has many times observed thin layers of darkly stained sand charged with petroleum, interstratified with sands of almost the same composition but quite devoid of petroleum, and light grey in colour, which shows that the oil was derived from some material permeating the sediment of a limited period. At other points in the same series thick deposits of the same kind of petroleum-charged sands have been penetrated, and oil in large quantities obtained.

The occasional occurrence of bitumen in vesicular volcanic rocks where they are not in contact with petroliferous formations may be due to the condensation of emanations of hydrocarbons at the time of the disturbances resulting in their upheaval, but in no case do such rocks yield more than a trace of petroleum. Volcanic rocks are obviously unsuitable reservoirs for fluids were petroleum produced beneath and amidst them, and it appears more than a coincidence that 85 per cent. of the world's supply of petroleum in 1907 was obtained from beds of a recent (Tertiary) geological age, which are generally underlain by an enormous thickness of older unpetroliferous sedimentary strata which would have arrested the upward movement of any subterranean products.

Theories involving intricate chemical reactions based only upon theoretical considerations have found no acceptance with persons having an intimate knowledge of petroleum, although many of the suggested inorganic reactions are extremely ingenious, and show what persistent efforts to produce oil have followed a conviction that it has been derived from mineral matter.

Organic Origin of Petroleum.—The organic origin of petroleum is now almost universally accepted, although there is no general agreement as to its origin from vegetable or animal matter, or whether it was produced in the beds in which it is now found or introduced subsequently by a process of distillation of underlying seams of organic matter. It is quite likely that petroleum has a dual origin, and is sometimes formed from one and sometimes from another source, and it is quite certain that no single explanation will afford an explanation for the formation of petroleum in all regions. Similarly some supplies of petròleum may have an adventitious origin and others an indigenous one.

At one time very erroneous ideas were held as to the porosity of mineral masses, but modern research has proved that all rocks are porous and can absorb considerable volumes of fluids under high pressure; whilst the more common sands, sandstones, and limestones are capable of absorbing and retaining from 10 to 50 per cent. of their bulk of water. These capacities alone are sufficient to account for a production equal to that obtained from most oil-fields, and even for the large productions obtained in a short interval when the great gas pressures under which the oil is secreted are considered. The great artesian flows of water which are obtained from wells of small diameter in suitable artesian basins, without the aid of gas pressure, exemplify the porosity of certain sands and the ease with which subterranean friction is overcome, and even in dense, almost impervious, rocks great supplies of water are often obtained when fissures are penetrated. In the case of petroleum, fissures also play no unimportant part in the distribution of the fluids as explained on p. 57, although sometimes their value is the reverse of favourable.

In considering the productive character of strata one must not overlook the fact that great supplies of petroleum remain unrecovered, partly through failure to distribute the wells uniformly, and partly to the commercial impossibility of

draining the beds completely. Petroleum, unlike water, being viscous, will not flow a long distance even under gas pressure when the head is reduced, and the denser and more viscous the oil the less distance will the oil flow; consequently, when estimating the capacity of a stratum from statistics of production, considerable allowances must be made for a large proportion of unextracted petroleum. Under any circumstances it is difficult to make estimations of such a character, as the lateral variation in porosity, texture, and thickness of beds is often considerable. Considering all factors, it appears probable that in the case of some oil-fields, as Russia, Roumania, and Borneo, the porosity has exceeded the natural capacity of sands of the grade occurring locally, and that the oil has been produced in the beds themselves and replaced organic substances which gave the beds exceptional porosity, but which have been converted by processes of decomposition into petroleum.

Many argillaceous shales which are permeated with organic matter yield under distillation fair grade petroleums,* and it is conceivable that natural forces may have resulted in the less violent, and therefore more perfect, distillation of such shales under certain circumstances, the produced hydrocarbons displacing water and saturating porous strata in the vicinity.

Amidst the Scotch shales small quantities of liquid hydrocarbon have been met with, especially near intrusive rocks where a natural process of distillation has proceeded, but usually where such bituminous and carbonaceous shales occur there is no petroleum in appreciable quantities. In some oil-fields the clays are saturated with petroleum, but in most cases the clays and shales dispersed amidst an oil-bearing series are not petroliferous, and appear as dry compact formations.

The distillation of wood, lignite, or coal results in the formation of hydrocarbons both gaseous and liquid, and the

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* See p. 118.

suitable distillation of almost any vegetable matter will result in some such products. Bituminous shales are common amongst the coal measures, and they have at times been mined and distilled for the production of petroleum and sulphate of ammonia. Methane or marsh gas, one of the most common hydrocarbons that accompany petroleum everywhere, is frequently emitted in great volumes from the coal measures, and enormous "blow-outs" of this gas have caused a cessation of mining in some collieries for many months. These accumulations of methane usually occur in faulted or fissured and disturbed ground, illustrating how the terrestrial circulation of hydrocarbons is directly affected by such circumstances. There are also occasional occurrences of crude petroleum in coal pits, and many barrels daily have been collected from exudations in some of the West of England and Northumberland collieries.

Such accumulations of gaseous and liquid hydrocarbons, allied to those constituting crude petroleums, indicate the possible production of mineral oils from a vegetable source, and definitely and conclusively prove that such products can be produced in nature from such matter. The frequency with which petroleum fields are associated with coal and the common occurrence of lignites in the oil-bearing series of the world are, at least, instructive sources of speculation. The highly bituminous coals are not after all so very far removed from certain native bitumens, and one can imagine a modified process by which, under certain conditions, a product more closely resembling petroleum could have been formed.

Many of the strata in some oil-bearing regions contain great quantities of petrified wood, both silicified and calcified, and whole tree trunks may be observed embedded in the strata. In Peru, for instance, trunks of trees may be found lying horizontally in the strata, having evidently been carried by currents and deposited, as the wood is largely perforated by boring insects, and around Spindle Top, Texas, wells have passed through thick deposits of vegetable matter and tree

trunks.* In the Baku fields well-preserved fragments of partially petrified wood are found embedded in nodules raised from the wells, but in very few cases does the wood exhibit a bituminous character. The Government geologist of Trinidad informed the author that he had traced the lateral variation of a bed of lignite into a bituminous formation, which, if confirmed, strongly favours a vegetable origin of the oil and bitumen in that country at least; and in both that island and Barbados the author has inspected great masses of burnt shales in which the imprints of millions of leaves are frequently to be observed (see p. 117).

In the Kuban oil districts of Russia it has been recorded by Mr Winda, a Russian geologist of distinction, that the petroleum impregnations are exclusively confined to a series of Oligocene strata, wherein the remains of fish are abundant, and that where these fossils are absent neither the clays nor the neighbouring sands are petroliferous.

Many of the great supplies of petroleum may have originated from the suitable decomposition of animal matter which has been entirely transformed into other substances leaving no other trace of its original presence. That accumulations of animal life sufficiently great to account for the largest supplies of petroleum are possible may be gleaned from the great beds of chalk and limestone formed solely from the skeletons or shells of marine life. Other forms of life with less lasting structure may have been deposited with sedimentary matter in suitable situations and circumstances, and transformed into petroleum during subsequent ages by processes of nature.

Composition and Characteristics of Petroleum and Natural Gas.—Petroleum as it is usually obtained for commercial purposes in the oil-fields of the world has a specific

* See "Oil-Fields of the Texas-Louisiana Gulf Coastal Plain," U.S. Survey, 1908.

gravity varying from .780 to 1.0, but the more common petroleums have a specific gravity between 0.850 and 0.940 when raised from the earth, although sometimes moderate supplies of amber-coloured oils (" white oil "), with a specific gravity of about .780, are obtained. On exposure to the atmosphere crude petroleum undergoes a change through evaporation and oxidation, and steadily increases in density.

Petroleum is a viscous fluid which emits a distinctive but pleasant odour, though sometimes when contaminated with sulphur compounds a most disagreeable and even offensive odour is emitted. The colour of petroleum, when viewed by transmitted light, varies considerably, from yellow, green, and red to reddish brown, and through various shades of brown to black, and by reflected light crude petroleum usually exhibits a green fluorescence which is commonly known as " bloom."

The so-called " white " oils occasionally met with in oil-fields are usually transparent and amber tinted, and are evidently infiltration products of darker varieties which are usually found in the neighbourhood. They are rarely found in considerable quantities, but the author is inclined to believe that they are very commonly struck in small quantities during the drilling of wells, although only occasionally recognised by the drillers on account of their admixture with slush and their resemblance to the dirty waters raised from the well.

It has been proved experimentally that dark crude oils can not only be deprived of their colour by forced filtration through fuller's earth or clay, but that a certain fractionisation can be accomplished also, and there is no doubt that a similar natural process has proceeded in the earth where the white oils are found in the clays separating strata yielding dark oils.

Occasionally considerable quantities of the "white" oils have been found, but the only district which has regularly yielded this type in great quantities is Surakhany, on the outskirts of the Romany oil-field of Baku, where wells yielding as much as 48 tons of white oil daily have been struck, but even there the

relationship with the darker crudes has been established by the discovery of important deposits of the ordinary Baku oils at greater depths. A sample of Surakhany "white" oil, taken by the author from a flowing well which gave in one year about 10,000 tons of similar oil, had the following characteristics:—

Colour, pale amber, clear and transparent.
Specific gravity, .780.
Odour, ethereal and pleasant.

More than 50 per cent. distils over below 150 deg. Cent., and practically all is vaporised below 300 deg. Cent.

A sample of "white" oil from the Los Angeles district of California having a specific gravity of .810 yielded on distillation:—

Below 150 deg. Cent.	- -	51 per cent.,	sp. gr.	.783
From 150 to 270 deg. Cent.	-	43 ,,	,,	.834
Above 270 deg. Cent.	- -	4 ,,		

Some oil from the Placenta Canyon of California had a specific gravity of .740.

"White" oils have frequently been recorded in Russian, Roumanian, and American wells, and their occasional and erratic occurrence in regions where dark oils are almost exclusively produced serves to support the filtration explanation submitted.

Some crude oils of great purity and viscosity, which realise in a crude state from £6 to £10 a ton, are found in the States of Wyoming, Texas (Jack County), Pennsylvania (Franklin), and West Virginia (Petroleum) in North America, and are employed direct as lubricating oils after filtration to remove particles of sand. One such black viscous Wyoming oil, of a specific gravity of 0.966, gave the following results on distillation:—

19.0	per cent.	lubricating	oil,	0.842 to 0.847	specific gravity.
45.0	„	„	„	0.926 to 0.935	„
12.5	„	„	„	0.957	„
14.5	„	coke.			
9.0	„	loss.			
100.0					

Petroleum is composed essentially of hydrogen and carbon united in the form of hydrocarbons of variable composition and complex constitution, although it is often contaminated with small proportions of oxygen, sulphur, and nitrogen. Different petroleums are composed of a mixture of different hydrocarbons, but generally a main line of distinction is drawn between (*a*) asphaltic oils—those which yield, on slow distillation, a dark asphaltic residue which is readily attacked by acids and dissolves in usual solvents; and (*b*) paraffin oils—those which yield on reduction to a low temperature an appreciable proportion of light-coloured, solid hydrocarbons, chiefly of the paraffin series, which are not readily attacked by acids and normal solvents.

No distinct line can be drawn between "asphaltic" and "paraffin" oils, and the terms are only used for convenience of distinction. Nearly all asphaltic oils contain traces of solid paraffins, and many essentially paraffin oils contain asphaltic products; but rarely do crude petroleums of either class contain any considerable proportion of the other class. Some of the Mexican oils are of the mixed type, and the presence of a certain proportion of solid hydrocarbons in a typically asphaltic oil considerably complicates the process of refining.

All crude petroleums, whether of an asphaltic or paraffin character, are composed of a mixture of hydrocarbons of different boiling points and densities (specific gravities), so that when subjected to heat the various hydrocarbons constituting the oil tend to be evolved as the temperature of their boiling points is approached. Anything like a complete separation of the components of such a complex substance as petroleum presents considerable difficulty owing to

several causes, such as the presence of two substances, the boiling points of which are very close together; the presence of one or more components in relatively small quantity; and the formation of mixtures of constant boiling point, all of which causes of difficulty are likely to be accentuated by the presence or formation during distillation of isomers as explained below. For these reasons and because the number of hydrocarbons and their range of boiling points is considerable a steady distillation ensues without periods of intermission as the temperature rises, until towards the end of the operation when the heat is very great only a small proportion of heavy residuum remains, which is converted into coke if the temperature is raised sufficiently high. By passing the evolved gases through a condenser kept cool by means of a constant circulation of water, the various products may be condensed and separated into a mixture of hydrocarbons having boiling points and specific gravities between certain limits. Mixtures of hydrocarbons so condensed between fixed limits of density and flash point are given trade names under which they are marketed.

The isolation and determination of the hydrocarbons composing an oil is a very difficult operation which is considerably complicated by (*a*) the existence of what are known as isomers, *i.e.*, hydrocarbons of identically the same quantitative chemical composition but possessing different qualities on account of the different relationship of the atoms in the molecule; (*b*) the occurrence of a phenomenon termed "cracking," whereby during the process of distillation hydrocarbons of one composition are reduced to lower members of the same series or even converted into other series of hydrocarbons. Oils of similar general character do not necessarily consist of a mixture of the same hydrocarbons; thus two oils yielding about the same proportion of equally good benzine, lamp oil, and lubricating oil may be composed of a mixture of quite different hydrocarbons belonging to totally distinct chemical series.

The chemistry of petroleum is exceedingly intricate, and there is no intention of entering into any description in this work, but a few details may give a general idea of the main characters of petroleum. Members of the paraffin series of hydrocarbons, C_nH_{2n+2}, form one of the chief constituents of oil all over the world, although the higher members which are solid at normal temperatures are comparatively rare, but methane, CH_4, the lowest member of the paraffin series, which is gaseous, is always present in large quantities dissolved in the oil, and it forms the chief constituent of natural gas.

Methane is a saturated hydrocarbon containing the maximum percentage of hydrogen (75 per cent.) and smallest percentage of carbon (25 per cent.) by weight possible, and all higher members of the same series contain a larger percentage of carbon and a lower percentage of hydrogen. Many of the finest oils in the world are composed largely of the normal paraffins (C_nH_{2n+2}), the higher members of the series being solid, and known as paraffin scale after extraction.

The Russian oils of Baku appear to be largely built up of hydrocarbons, known as naphthenes, being isomers of the olefine series, C_nH_{2n}, although there are many others, including the C_nH_{2n-6}, or benzine series, in the more volatile portion of some oils. Mr Hurst has pointed out that the cause of the Russian oils having a lower flash point for a definite specific gravity than American oils is on account of the prevalence of naphthenes, which have a lower flash point compared with their specific gravities than either paraffins or normal olefines.

Comparisons of specific gravity and the arbitrary designation of Benzine, Illuminating and Lubricating oils over a fixed range of temperatures of distillation give but an approximate idea of the actual constitution of the oil, although such divisions are useful for rough comparisons. It is usual, for general convenience, to adopt Engler's method of designating as benzine those products which distil up to 150 deg. Cent.

TABLE XXVIII.—COMPARISON OF REPRESENTATIVE CRUDE PETROLEUMS FROM DIFFERENT OIL-FIELDS.

Field from which Oil is taken.	Specific Gravity.	Distillate in Volume.					Remarks.
		0° to 150° Cent.		150° to 300° Cent.		300° Cent. and above.	
		Per cent.	Sp. Gr.	Per cent.	Sp. Gr.	Per cent.	
Pennsylvania - - -	0.820	21.0	0.718	41.0	0.798	37.0	Edeleanau.
Ohio (Lima) - - -	0.838	9.7	0.728	37.1	0.787	52.12	Mabery.
Illinois (Randolph County) -	0.842	14.0	0.729	37.0	0.797	49.0	2.40 % Sulphur.
Kansas (Wilson County) -	0.835	19.0	0.720	38.1	0.808	42.8	... ...
Oklahoma (Glenn Pool) -	0.846	8.5	0.756	42.0	0.800	49.9	6.98 % Paraffin.
West Virginia - - -	0.787	16.5	0.711	41.0	0.769	34.5	5 % Paraffin.
California (Coalinga) - -	0.915	5.7	0.771	34.1	0.858	60.2	0.45 % Sulphur, Cooper.
„ (Kern River) -	0.961	...	...	20.2	0.862	79.8	0.94 % Sulphur, Cooper.
„ (Los Angeles) -	0.971	...	...	26.3	0.885	73.7	1.18 % Sulphur, Cooper.
„ (Whittier Field) -	0.929	4.2	0.773	38.3	0.870	57.5	Prutzman.
Texas - - - - -	0.910	2.9	0.794	39.8	0.876	57.3	... ...
Russia (Grosny) - - -	0.869	13.4	0.730	25.6	0.808	60.6	... ...
Roumania (Bushtenari) -	0.8420	35.4	0.734	29.8	0.840	34.8	Edeleanau.
„ (Campina) - -	0.824	37.7	0.729	30.5	0.823	31.8	Edeleanau.
Burma (Yenangyat) - -	0.840	17.8	...	49.4	...	...	Engler.
Italy (Villeia) - - -	0.787	55.0	...	42.0	...	...	Light Brown.
Japan (Echigo) - - -	0.862	21.8	...	38.8	...	39.9	Paraffin, Mabery.

or 302 deg. Fahr., and as illuminating oils those distilling between 150 and 300 deg. Cent. (302 to 572 deg. Fahr.). Such a rough separation is approximate only, but as a rule good lamp oils contain few fractions distilling below 150 deg. Cent., and few above 300 deg. Cent., although much depends upon the character of the hydrocarbons. Russian kerosene contains fractions within close limits of 150 and 270 deg. Cent., and some Roumanian crude oils yield 42 per cent. of good lamp oil between 130 and 310 deg. Cent., with a specific gravity of only .808 after refining.

Table XXVIII. gives the percentage by volume yielded by a number of crude oils from different oil-fields between 0-150 deg. Cent. and 150-300 deg. Cent., the specific gravity of the distillates being in most cases given. A comparison will show the wide difference in volume and density of the distillates from different oils.

It will be found that the specific gravities and flash points of distillates from different crude petroleums within defined limits of temperature vary considerably; indeed, rarely do crude oils from two separated fields yield the same results, whilst often oils from adjacent wells have a totally different composition of hydrocarbons. Isolated samples of Roumanian oils have yielded 29 per cent. of fractions below 80 deg. Cent. where the usual percentage is 10 to 12.

Table XXIX. has been prepared to illustrate the difference in the character of the hydrocarbons composing the lighter fractions within the same limits of temperature of four representative Roumanian oils, from which it will be noticed what a wide difference there is, not only in the percentage yield of the respective fractions, but also in the density of the products. The lighter fractions have been selected, as owing to the lower temperature of distillation and the less complex character of the distillates, less dissociation will have taken place during the distillation than with oils of greater density.

TABLE XXIX.—PROPERTIES OF DISTILLATES BETWEEN 0 AND 150 DEG. CENT. OF FOUR REPRESENTATIVE ROUMANIAN PETROLEUMS.*

Temperature of Distillation.	Tetreani.		Bushtenari.		Campina.		Baicoi.	
	Per cent. by Weight.	Specific Gravity.	Per Cent. by Weight.	Specific Gravity	Per cent by Weight.	Specific Gravity.	Per cent. by Weight.	Specific Gravity.
Deg. Cent.								
0- 50	11.88	0.640	4.00	0.647	0.77	0.651	3.60	0.634
50- 60	4.29	0.666	0.70	0.668	2.40	2.679	5.95	0.658
60- 70	7.29	0.706	3.74	0.681	4.90	0.686	5.92	0.678
70- 80	4.95	0.725	4.25	0.707	3.85	0.705	4.62	0.696
80- 90	8.25	0.737	4.66	0.726	7.92	0.728	11.00	0.719
90-100	12.21	0.744	13.70	0.735	17.90	0.732	13.20	0.732
100-110	14.20	0.753	24.24	0.745	9.25	0.739	13.40	0.745
110-120	10.89	0.758	15.93	0.755	9.05	0.747	11.20	0.753
120-130	8.58	0.764	10.12	0.760	17.34	0.756	11.75	0.755
130-140	8.25	0.773	9.34	0.775	10.32	0.765	10.50	0.766
140-150	8.58	0.779	9.32	0.782	16.28	0.776	8.86	0.775

The almost limitless possible number of hydrocarbons with their isomers, especially in the higher members of series, only a comparatively few of which have yet been isolated, presents endless combinations and possibilities. The boiling points and densities of the hydrocarbons increase with the complexity of the molecule, and many of the high members of certain series have a specific gravity approaching unity, and their boiling points cannot be reached, except, under a vacuum, owing to dissociation.

Table XXX. gives the percentage by weight of the fractions in four representative refined illuminating oils, with the specific gravities, flash points, and fire points of each fraction, which also clearly illustrates the difference in character of the hydrocarbons composing lamp oils of similar general qualities from different sources used for the same purpose.

* Taken from "A Study of Roumanian Petroleum," by Edeleanau and Tanasesco.

TABLE XXX.—RELATIONSHIP OF FRACTIONS BETWEEN 140 AND 300 DEG. CENT.,* IN FOUR REPRESENTATIVE ILLUMINATING OILS.

Origin and Characteristics of Oil.	American (Water White).				Russia.				Roumania.				Texas.							
	Specific Gravity, .7954. Boiling Point, 125° Cent. Flash Point, 42° Cent. Fire Point, 55° Cent.				Specific Gravity, .825. Boiling Point, 130° Cent. F ash Point, 31° Cent. Fire Point, 47° Cent.				Specific Gravity, .811. Boiling Point, 112° Cent. Flash Point, 26° Cent. Fire Point, 38° Cent.				Specific Gravity, .819. Boiling Point, 120° Cent. Flash Point, 30° Cent. Fire Point, 37° Cent.				Specific Gravity, .812. Boiling Point, 110° Cent. Flash Point, 27° Cent. Fire Point, 39° Cent.			
Fractions up to	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.
Deg. Cent.			Deg.	Deg.			Deg.	Deg.			Deg.	Deg.			Deg.	Deg.			Deg.	Deg.
140	...	...	...	...	...	...	...	...	3.38	.766	...	...	...	...	...	...	1.65	.759	...	...
150	1.50	.756	...	...	2.77	.779	...	...	8.00	.733	...	...	3.33	.768	...	...	5.42	.764	...	...
160	2.49	.759	14	15	5.57	.784	...	...	13.60	.780	16	19	6.68	.777	...	...	6.16	.770	...	...
170	5.22	.766	22	23	9.39	.792	16	...	12.45	.7895	22.4	29	12.36	.790	17	18	9.70	.7775	21	24
180	7.29	.772	28	31	7.57	.802	24	30	10.48	.7975	33	39	13.73	.799	28	31	4.27	.785	26	30
190	8.55	.778	36	42	7.23	.809	33	40	7.08	.805	43	51	13.00	.810	38	42	4.96	.791	31	37
200	9.44	.784	45	53	6.98	.816	42	48	6.54	.813	52	59	11.48	.820	49	52	4.29	.796	37	42
210	8.22	.790	53	63	6.84	.823	51	58	6.24	.821	60	67	10.41	.830	59	63	4.24	.8015	44	50
220	7.89	.796	62	72	6.83	.829	59	67	5.67	.8285	67	75	9.52	.839	68	72	4.94	.808	51	57
230	7.74	.801	70	82	6.72	.8345	67	75	4.48	.836	73	80	8.50	.847	75	80	4.95	.813	59	67
240	7.02	.806	80	90	6.57	.839	75	84	4.28	.843	78	86	3.83	.855	82	87	4.96	.8185	67	77
250	6.37	.810	85	97	6.45	.843	83	92	3.62	.849	82	90	3.31	.863	88	94	5.16	.8235	75	84
260	4.50	.814	95	103	6.44	.848	91	101	2.91	.855	86	96	2.00	.870	94	100	5.30	.828	83	94
270	3.77	.818	103	109	6.20	.852	99	109	2.95	.861	90	104	0.82	.877	99	106	5.65	.833	92	102
280	2.77	.822	110	117	4.27	.857	107	117	2.55	.866	94	108	...	...	...	...	6.25	.8265	102	113
290	2.08	.826	117	124	4.12	.861	114	125	1.37	.870	97	114	...	...	...	...	5.10	.8405	113	124
300	1.63	.830	125	132	2.42	.8645	120	133	0.99	.873	99	119	...	...	...	...	4.70	.844	124	137
Above 300	3.52	.843	112	119	3.03	.878	143	158	2.90	.885	124	143	0.60	.892	...	...	12.20	.857	139	151

* From paper read before the Petroleum Congress in Liège in 1902 by Dr Dvorkovitz.

The paraffins are the most stable and saturated hydrocarbons, and to the special prevalence of this series may be attributed the superiority of Pennsylvanian lamp oils over many other varieties. The carbon affinities in the paraffin molecule are satisfied to the fullest extent with hydrogen, but where such is not the case the hydrocarbons are unsaturated, and become more so with the complexity of the molecule in each series of hydrocarbons. The saturated hydrocarbons can be separated from the unsaturated by sulphuric acid, and the less saturated the hydrocarbons the more readily are they attacked by sulphuric acid.

The refining of lamp oils is undertaken to remove the more unsaturated hydrocarbons, as they impair the combustion of the oil and lead to the emission of disagreeable odours. The saturated and less unsaturated hydrocarbons are unaffected by sulphuric acid, but the more unsaturated are decomposed by sulphuric acid with which they either unite to form sulpho compounds, or they are converted into other hydrocarbons. The less complex character, and consequently more saturated condition, of the hydrocarbons in the more volatile fractions of most oils accounts for the diminished need for refining the lighter distillates of all crude oils.

Density of Oils.—The specific gravities of petroleum vary considerably even in the same district of an oil-field, but whilst this is sometimes due to local geological conditions, in many cases the variation is due to such causes as the age of the well, presence or absence of water with the oil, extent of exhaustion of the strata, &c. There is usually a sensible increase in density of petroleum when pumped from the field to the storages, being equivalent in the case of light crude oils in a warm climate to a loss of 5 per cent. When stored for long there is a continual loss by evaporation from light oils which increases their density, and in warm climates the tanks should be screened from the sun.

The specific gravity of oil in the United States is generally measured in degrees on the Baumé scale, but in most

countries the density of oils is compared with water as unity. The specific gravity is almost universally taken in the field by an hydrometer, when the density is read off a scale directly, and corrections applied for temperature, &c., but where extreme accuracy is needed either a specific gravity bottle or a set of hydrometers is used, each of which indicates a narrow range of densities over a long scale, in which case a pilot hydrometer is included to indicate the approximate density so that the correct instrument shall be selected without trial.

Table XXXI. gives the Baumé and specific gravity equivalents.

TABLE XXXI.—Table of Baumé and Specific Gravity Equivalents.

Baumé.	Specific Gravity.	Baumé.	Specific Gravity.	Baumé.	Specific Gravity.
10	1.0000	37	0.8395	64	0.7243
11	0.9930	38	0.8346	65	0.7205
12	0.9860	39	0.8299	66	0.7168
13	0.9790	40	0.8251	67	0.7133
14	0.9722	41	0.8204	68	0.7097
15	0.9658	42	0.8157	69	0.7061
16	0.9594	43	0.8110	70	0.7025
17	0.9530	44	0.8063	71	0.6990
18	0.9466	45	0.8017	72	0.6956
19	0.9402	46	0.7971	73	0.6923
20	0.9339	47	0.7927	74	0.6889
21	0.9280	48	0.7883	75	0.6856
22	0.9222	49	0.7838	76	0.6823
23	0.9163	50	0.7794	77	0.6789
24	0.9105	51	0.7752	78	0.6756
25	0.9047	52	0.7711	79	0.6722
26	0.8989	53	0.7670	80	0.6689
27	0.8930	54	0.7628	81	0.6656
28	0.8872	55	0.7587	82	0.6619
29	0.8814	56	0.7546	83	0.6583
30	0.8755	57	0.7508	84	0.6547
31	0.8702	58	0.7470	85	0.6511
32	0.8650	59	0.7432	86	0.6481
33	0.8597	60	0.7394	87	0.6451
34	0.8544	61	0.7557	88	0.6422
35	0.8492	62	0.7319	89	0.6392
36	0.8443	63	0.7281	90	0.6363

The coefficient of expansion of petroleum not only varies with different classes of oil of the same specific gravity but also with alterations of temperature, and the expansion of heavy oils is less than that of light oils. Owing to the variation of expansion with different oils it is usual to prepare tables to apply to special oils with which one is constantly engaged, giving the amount to be added to or subtracted from the observed specific gravity for each degree fall or rise of temperature above normal temperature, to reduce the specific gravity to normal temperature. The coefficient of expansion of crude oils varies between extreme limits of about .00085 for light grade crude, and .00065 per degree Cent. for heavier crudes (equal to .00047 and .00036 per degree Fahr.), and these values, when accurately determined by experiment, are added to or subtracted from the observed gravities to reduce to some normal basis for comparison. At increased temperatures the rate of expansion increases slightly, but it is usually neglected in crude oils estimations. Redwood states that the following corrections should be made for refined products:—

Products lighter than Kerosene - -	.00040 to .00048 per 1° Fahr.
Kerosene - -	.00040 „
Gas oils - -	.00036 „
Lubricating oils	.00034 „

Davis, in his "Petroleum Tables," which are generally used by shipowners for calculating cargoes of tank ships, gives the following corrections:—

For Benzine - - - -	.00045 per 1° Fahr.
„ Lamp oils (.795 to .825) -	.00040 „
„ Solar and light lubricating oils	.00038 „
„ Heavy lubricating oils -	.00035 „

Tables XXVIII., XXXII., XXXIII., give the specific gravities of a number of representative oils from different countries.

Ultimate Composition.—The ultimate composition of crude petroleum varies very little indeed, the percentage of carbon ranging from 84 to 86, and that of hydrogen from 11.5 to 14.5. Sulphur largely enters into the composition of some oils, and there are often appreciable proportions of oxygen and nitrogen. Table XXXII. gives a few ultimate analyses of petroleum collected from various sources.

TABLE XXXII.—ULTIMATE COMPOSITION OF REPRESENTATIVE PETROLEUMS.

Origin of Petroleum.	Specific Gravity.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.	Authority.
Pennsylvania - -	0.801	86.10	13.90	...	...	0.06	Engler.
Ohio - - -	0.827	85.42	14.59	0.064	...	..	Mabery and Dunn.
California (heavy) -	0.984	86.32	11.70	1.25	...	0.84	Mabery.
,, (light) -	0.846	86.24	13.08	...	...	...	,,
Texas (Beaumont) -	0.912	85.03	12.30	0.92		1.75	C. Richardson.
Roumania (Bushtenari) - -	...	86.30	13.32	...	...	0.18	Edeleanau.
Roumania (Campina) - - -	...	86.03	13.26	...	...	0.13	,,
Canada (Petrolia) -	...	83.94	13.37	...	...	0.99	Mabery.
Peru (Zorritos) -	0.850	86.08	13.06	0.071	0.748	0.041	...
Italy (Parma) -	0.786	84.00	13.40	...	1.80	...	Deville.
Russia (Baku) -	0.884	86.3	13.6	...	0.1	...	Redwood.
Galicia - - -	0.852	85.3	12.6	...	2.1	...	,,
Burma . - -	0.855	83.8	12.7	...	3.5	...	,,
East Indies (Java) -	0.088	87.1	12.0	...	0.9	...	,,

Calorific Value.—The calorific value of petroleum can be found by calculation from the ultimate composition, or it can be directly determined by combustion in a calorimeter. The results very closely coincide, and either is always sufficiently near for all commercial purposes for which comparisons are required. Petroleum cannot be readily burnt in ordinary calorimeters owing to the fierceness of the combustion, even when well mixed with absorptive substances to delay the action. The Mahler bomb type of calorimeter is the only safe and reliable instrument to use for liquid fuels, and a descrip-

tion of the method of use can be found in chemical works. In Table XXXIII. are given the calorific values of a number of selected oils representing characteristic types.

Calorific values are stated either in calories, which is the amount of heat required to raise 1 gramme of water from 0 deg. Cent. to 1 deg. Cent., or in British thermal units, which is the heat required to raise 1 lb. of water from 32 deg. Fahr. by 1 deg. Fahr. Calories per gramme can be converted into British thermal units per lb. by multiplying the former by 1.8.

TABLE XXXIII.—CALORIFIC VALUES OF REPRESENTATIVE PETROLEUMS.

Nature of Petroleum.	Specific Gravity.	Calorific Value, B.T.U.'s per lb.
West Virginia	0.841	18,400
Louisiana	0.939	19,300
Californian	(?)	18,742
„ (Coalinga)	0.915	17,500
„	0.948	18,675
Texas (Beaumont)	0.920	19,060
Russia (Baku)	0.884	20,600
Galicia	0.870	18,000
Roumania (Bushtenari) residue	(?)	19,600
„ (Campina) „	(?)	19,900
Burma	0.869	19,250
Peruvian (Negritos)	0.850	19,445
Italy (Parma)	0.786	18,200

Flash Point and Fire Test.—As all petroleums evolve inflammable gases at certain temperatures, careful investigations have been undertaken for the purpose of framing legislation to protect the public. Petroleum, like water and many other liquids, suffers a certain amount of evaporation at temperatures far below the boiling points of the hydrocarbons composing the product; indeed, high winds will cause considerable evaporation of oil exposed to the atmosphere, and some oils can be entirely evaporated at a temperature below zero by blowing cold air through them. It was formerly usual to gradually warm a sample of oil in a small open

vessel placed in a water bath, until a flash occurred when a lighted taper was held over the vessel. The temperature at which the flash took place was called the "flash point" of the oil, and by continuing the heat a point was reached when the oil took fire, and this was termed the "fire point." There is a considerable difference between the flash point and fire point of oils, amounting often to 25 to 30 deg. Fahr. in the case of illuminating oil.

Investigations showed that to obtain consistent results a system of testing must be standardised, as the flash point depended entirely upon the manner in which the test was applied. When made in an open vessel a much higher flash point was recorded than when tested in a closed vessel, the difference reaching usually 25 to 28 deg. Fahr. Eventually the Abel-Pensky flashing test instrument was introduced and accepted as a standard by the British and some other Governments, and tests properly conducted show uniform results, as the instrument assures identical conditions in every test. Corrections have to be made for variations of atmospheric pressure, the flash point being lower with increased altitude or fall of barometer. For each one inch of variation in the mercurial column there is a reduction or elevation of 1.6 deg. Fahr. in the flashing point. Full directions for use are given with flash-testing instruments as well as tables of corrections for barometric pressure.

The British standard flash point for lamp oil is 73 deg. Fahr. by the closed test, equal to about 100 deg. Fahr. open test.

Natural Gas.—Natural gas is extensively employed for both heating and illuminating purposes, especially in the United States, where it is often conveyed hundreds of miles in large mains under a high pressure. Natural gas has a calorific value far exceeding coal gas on account of the usual high percentage of methane, the combustion of which gas causes a high temperature. In 1905, the value of American natural gas—mainly obtained from the States of Pennsylvania,

West Virginia, Ohio, and Indiana—directed to useful employment was valued at about £8,000,000, even when the average cost was taken as low as eightpence (sixteen cents) per 1,000 cubic feet. The gas was obtained from some 17,000 wells, of which 14,600 were in the above-named four States.

The United States Geological Survey gives the analyses and particulars of average quality natural gas from different gas-fields, shown in Table XXXIV., where for the purpose of comparison the analyses of artificial gases are given also.

TABLE XXXIV.—ANALYSES OF CHARACTERISTIC NATURAL GASES AND COMPARISON WITH MANUFACTURED GASES.

Constituent.	Average, Pennsylvania and West Virginia.	Average, Ohio and Indiana.	Average, Kansas.	Average of Coal Gas.	Average of Water Gas.	Average, Producer Gas from Bituminous Coal.
Marsh gas, CH_4	80.85	93.60	93.65	40.00	2.00	2.05
Other hydrocarbons	14.00	.30	.25	4.00	.00	.04
Nitrogen	4.60	3.60	4.80	2.05	2.00	56.26
Carbon dioxide	.05	.20	.30	.45	4.00	2.60
Carbon monoxide	.40	.50	1.00	6.00	45.50	27.00
Hydrogen	.10	1.50	.00	46.00	45.00	12.00
Hydrogen sulphide	.00	.15	.00	.00	.00	.00
Oxygen	Trace	.15	.00	1.50	1.50	.05
Total	100.00	100.00	100.00	100.00	100.00	100.00
Pounds in 1,000 cubic feet	47.50	48.50	49.00	33.00	45.60	75.00
Specific gravity, air being 1	0.624	0.637	0.645	0.435	0.600	0.985
B.T.U. per cubic foot	1,145	1,095	1,100	755	350	155

Very complete investigations of West Virginia natural gas have been made by Professor Phillips of the Western University of Pennsylvania on behalf of the United States Geological Survey.

TABLE XXXV.—ANALYSES OF REPRESENTATIVE WEST VIRGINIAN NATURAL GASES.

Constituents.	Fredonia.	Sheffield.	Kane.	Wilcox.	Speechley.	Murrysville, Lyon's Run, near.	Racoon Creek.	Baden.	Houston.
Nitrogen	9.54	9.06	9.79	9.41	4.51	2.02	9.91	12.32	15.30
Carbon dioxide	0.41	0.30	0.20	0.21	0.05	0.20	Trace	0.41	0.44
Hydrogen	0	0	0	0	0	0	0	0	0
Ammonia	0	0	0	0	0	0	0	0	Trace
Oxygen	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Sulphuretted hydrogen	0	0	0	0	0	0	Trace	0	0
Paraffins	90.05	90.64	90.01	90.38	95.42	97.70	90.09	87.27	84.26
	100.00	100.00	100.00	100.00	99.98	99.92	100.00	100.00	100.00
The paraffins contained in these gas samples have the following composition by weight:—									
Carbon	78.14	76.69	76.77	76.52	77.11	74.96	76.42	76.48	76.68
Hydrogen	21.86	23.31	23.23	23.48	22.89	25.04	23.58	23.52	23.32
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table XXXV. is taken from this Report and gives the analyses of nine representative samples of West Virginian natural gas.

An analysis of West Virginian gas made by Mr C. D. Howard in which the hydrocarbons are distinguished is given in Table XXXVI.:—

TABLE XXXVI.—ANALYSIS OF PENNSYLVANIAN NATURAL GAS (BIG INJUN SAND).

	Sample No. 1.		Sample No. 1.
Carbon dioxide (CO_2)	0.006	Carbon bisulphide (CS_2)	None.
Carbon monoxide (CO)	0.4	Sulphuretted hydrogen (H_2S)	"
Oxygen (O)	0.2	Moisture (grains in 100 cubic feet)	17.72
Hydrogen (H)	Trace.	Total sulphur (grains in 100 cubic feet)	0.182
Heavy hydrocarbons	0.4	Total paraffins	95.54
Ethane (C_2H_6)	14.60	B.T.U.'s per cubic foot	1142.6
Methane (CH_4)	80.94		
Nitrogen (N)	3.46		
Ammonia (NH_3)	None.		

From the great gas-fields of Surakhany on the outskirts of the Romany oil-field of Baku as much as 16,000,000 cubic feet of natural gas daily was piped to the oil-fields for use as fuel in Lancashire boilers, but in 1908 there was an inclination to disregard the gas and drill deeper in expectation of striking petroleum beneath the gas strata. The composition of the Surakhany natural gas approximates to that of the American fields in composition.

Table XXXVII. gives the analyses of several samples of Russian and other natural gas.

It will be observed that the Russian oil-well gases vary considerably in composition, and some contain large proportions of carbon dioxide and nitrogen. Wells yielding only nitrogen gas have been reported in America. Direct tests, made by Thompson and Hunter, of the volumes of gas issuing from bailing wells in the Russian oil-fields of Baku and Grosny showed extremes of 20,000 and 130,000 cubic feet a day, the average yield of nineteen wells in Bibi-Eibat being 43,200 cubic feet a day; and actual tests of nineteen

pumping and bailing wells in the Grosny oil-field showed extreme yields of 10,000 and 402,000 cubic feet daily, with an average of 85,000 cubic feet daily per well.

TABLE XXXVII.—ANALYSES OF RUSSIAN AND OTHER NATURAL GASES.

Origin of Gas.	CH_4.	CO_2.	O.	N.	Other Hydro-carbons.	Authority.
Surakhany (Russia)	93.25	4.53	0.36	0.49	1.37	Baku Technical Society
" "	93.99	4.00	0.42	0.58	1.01	" "
" "	93.47	4.09	0.41	0.60	1.43	" "
Saboontchy (Baku)	66.90	28.50	0.80	3.20	0.60	" "
" "	72.30	18.40	1.80	6.80	0.70	" "
" "	51.90	37.80	1.40	6.50	2.40	" "
Bibi-Eibat "	82.20	12.80	0.80	3.00	4.20	" "
" "	58.40	22.80	3.80	14.40	0.60	" "
" "	86.33	9.96	0.19	0.72	28.80	" "
" "	87.80	8.40	0.20	0.70	2.80	" "
" "	89.00	9.80	0.10	0.30	0.20	" "
Grosny (Russia) -	56.30	6.90	...	9.60	25.40	Grosny Laboratory.
" " -	90.00	2.60	...	6.60	0.10	"
Taman Peninsula -	97.87	2.11	...	...	...	Bunsen.
Italy - - -	96.50	3.50	...	...	...	Schmidt.
" - - -	98.85	0.74	...	0.41	...	"
Canada (Ontario) -	92.20	1.40	...	5.59	?	Shuttleworth.

Uses of Petroleum Products.—Some heavy crude petroleum containing a paucity of the more valuable products and having a high flash point are used direct as liquid fuel and command a ready sale at a price 50 per cent. above that of good quality coal in any market in which they may be introduced. Texas and California furnish an abundance of such oils, and Russian oils yield a large percentage of fuel oils after extraction of some 30 per cent. of light or intermediate fractions. As fuel, however, oil can command but a low price, except in a few isolated cases where solid fuel is exceptionally expensive; and operators in oil-fields of medium productive capacity cannot remuneratively produce oil at such prices. It is usual to extract the lighter and more valuable portions of the crude for the production of petroleum

spirit, illuminating oils, lubricants, and also paraffin wax when this latter is present. The combustion of liquid fuel is explained in Chapter X., and the distillation and refining of petroleum is briefly described on pp. 155 to 162.

From some light crude petroleums, often with a flash point below 32 deg. Fahr. (0 deg. Cent.), exceedingly light distillates can be obtained, which spontaneously evaporate when exposed to the atmosphere. Some such distillates have a specific gravity of only .590 to .620 and are used as anæsthetics, solvents, cleaning solutions, and are employed in some types of carburetted air plants. The heavier spirits, of a specific gravity of .680 to .750, are now extensively employed for internal combustion engines on automobiles and motor boats, and in the highest grades fully 90 per cent. of the spirit has a boiling point below 100 deg. Cent. The East Indian (Shell) spirit of .740 specific gravity has as low a boiling point as the American spirit of .700 specific gravity, demonstrating the wide difference in certain physical characters between two oils suitable for the same purpose.

The chief desideratum of distillation is generally illuminating oil, which has a specific gravity of .800 to .820, boiling points between 150 and 300 deg. Cent., and flash points of 70 to 150 deg. Fahr. The distillates that can be included under lamp oils constitute from 50 to 70 per cent. of certain crude oils, whilst in low grades of petroleum not more than 15 to 30 per cent. of medium quality illuminant can be obtained. Purified oils of the character described will generally burn with complete combustion in a lamp by capillary action up a wick, provided ample air is suitably admitted for combustion, but modern ingenuity has devised means of vaporising, not only lighter oils but ordinary lamp oils, and burning the gaseous products beneath incandescent mantles. By this system a greatly increased luminosity is obtained with a reduced expenditure of oil, and an extended use of such lamps is foreshadowed.

The .680 spirit can be used in the "Petrolite" lamp, which

consists of a porous block which absorbs the spirit and through which air is drawn and thereby carburetted by the natural heat of the flame. The carburetted air burns beneath an incandescent mantle, and the absolute safety of the lamp is assured by the absence of any loose liquid and the extinction of the flame at the instant the lamp is placed out of the vertical. The latest incandescent oil lamp is of the inverted type and it is claimed that a unit of light can be obtained at a lower cost than by any other illuminant. With oil at sixpence a gallon 1,000 candle power is estimated to cost three-eighths of a penny per hour.

There has been largely introduced during the last few years carburetted air machines which automatically produce from benzine a combustible mixture of air and gas which can be led along pipes and burnt beneath incandescent mantles. The air only contains about 1.6 per cent. of hydrocarbon vapour and will not burn unless broken up by passage through a special burner. The plant is worked by a small hot-air engine and is automatically controlled to supply only the demand created, and it is claimed that 1,000 candle-power can be generated at a cost of $\frac{4}{5}$d. per hour. Improvements permit heavier products to be utilised for carburetting, but the real difficulty is to avoid the recondensation of the absorbed hydrocarbons.

Kerosene is largely used for heating stoves and cooking ranges besides illuminating purposes, and in certain types of oil engines its use is general.

An intermediate distillate between illuminating and lubricating oils, known as solar oil, is largely sold for enriching gas made from low grade coals, and is especially used as the carburetting agent for the production of carburetted water gas in gas works. Water gas is produced by the passage of steam over incandescent coke, and it is carburetted to give it the necessary illuminating power by mixture with the gas oils in hot chambers, when complete gasification is ensured.

Numerous varieties of lubricating oils as well as vaseline,

paraffin wax, and other materials are prepared from certain distillates of particular oils which lend themselves to special treatments. The vaseline is used in pharmacy, and the paraffin wax, after purification with charcoal and separation into qualities according to melting point, is largely used in the manufacture of candles, insulating materials, chewing gum, &c.

Almost daily extended and often remarkable uses for petroleum products are found. The liberal use of oil on rough seas will often save a distressed ship from destruction by preventing the waves from breaking over the vessel, and the judicious application of certain oil products has been proved to very materially extend the life of macadamised roads, besides acting as an effective dust preventer. In tropical countries increasing use of petroleum is made to diminish the breeding of mosquitoes in swampy lands, a film of oil on the surface of water preventing the larvæ from breathing, and choking up their air passages.

Petroleum is used in the preparation of insecticides by emulsions with other chemicals. An important employment for certain residual products is the manufacture of waterproof compositions for treating felt, paper, or other substances which are sold as bitumen sheeting, &c.

One of the most extraordinary uses to which oil has recently been applied is the concentration of mineral ores, by which means the mineral contents of low grade ores can be extracted from the gangue. The Elmore ore concentration depends upon the mixture of well-crushed ore with an emulsion of oil and water by agitation in a vessel under a partial vacuum, when the well-known affinity of oil for metals leads to the particles of mineral matter becoming clothed with a film of oil, and rising to the surface of the liquid with the oil, whilst the unmineralised portion or gangue is precipitated.

Distillation of Petroleum.—The distillation and refining of petroleum can only be undertaken on a commercial scale

after consultation with qualified chemical specialists, and the execution of many preliminary distillations of characteristic samples of the product to be treated. Only a brief outline of the usual methods adopted will be given, and readers needing information are referred to chemical works dealing with the subject, of which, however, there are very few.

Some high grade crude oils are simply exposed to heat from a steam coil, and "reduced" in open pans until the desired viscosity and freedom from moisture is reached to fulfil the duties for which the particular oil is being made, whilst a few natural oils are used direct in their crude state for lubricating purposes after filtration to remove siliceous particles. Where crude petroleum is not employed direct for fuel or other purposes, it is subjected to a process of distillation whereby the various components of the oil are first expelled and then condensed to form distillates within certain ranges of density and flash point. The crude oil, sometimes previously warmed by waste heat, is introduced into steel cylindrical stills of varying design, heated by flues beneath, and the gaseous products of distillation are conducted from a dome above the still along pipes into a condenser. At first only products of low density pass over, but as the temperature of the still rises, denser distillates are expelled and are condensed. In the tail house leading from the condenser the condensed fluid discharges into a pipe from which there are a number of outlets, each controlled by a cock, and each leading to a separate storage tank, so that an attendant stationed there is able to deflect the products to the requisite tanks as the distillation proceeds, and the density of the oil varies.

The above description sounds very simple, but there are many details which require consideration, and which lead to considerable necessary modification in the normal plant. Some oils foam badly, especially if contaminated with water, and unless special precautions are taken, much crude oil is carried over from the stills with the distillates. When the

temperature of the still is over 300 deg. Cent., and only the dense constituents of the crude remain, considerable dissociation of the oil will take place unless distillation is assisted with the aid of steam. Steam is now almost universally employed, and it is found that besides reducing the temperature of distillation and keeping the viscous fluid in a state of motion, it assists the removal of the heavy distillates, and carries them away from the still with less dissociation. Mr D. R. Stewart * thus ably describes the use of steam in distilling:—"Water converted into steam expands seventeen hundred times. Our oil expands only one to two hundred times, and when distilled without steam, a great deal of oil has to be evaporated before the vapours mount to the exit pipe. This specific heat and heat of vaporisation are not great, and they readily condense on the top of the still and fall back, and be re-distilled with some decomposition." The steam is admitted by a perforated pipe which extends the full length of the still base, and when the temperature of distillation is high, as in the production of lubricating oils, it is superheated to the temperature of the oil before admission.

If products of greater density than solar oils are to be distilled it is unusual to carry out a complete distillation down to the lubricating oils in the same still, owing to the high temperature needed, but the residuum of the illuminating oil stills is transferred to others of special design for the extraction of the lubricating oils, when, in addition to steam, a partial vacuum is also maintained in the stills to diminish the temperature of distillation and avoid dissociation and burning.

The process of "cracking" is also made much use of in modern refineries, whereby a large proportion of lighter products is obtained than would otherwise be the case. Cracking is brought about by raising the temperature of the

* "The Oil Shales of the Lothians."

oil in the still above the normal height for the distillate being collected and leaving the upper exterior surface of the still exposed to the atmosphere, so that part of the products of distillation are thereby condensed and caused to fall back into the hot fluid. The result of the action is the reduction of hydrocarbons into products of lower density and boiling point, accompanied, however, by the formation of a certain amount of permanent gas. The exact action of "cracking" seems little understood, and it is generally stated that "cracked" oils are inferior to uncracked, and that they require more refining.

In Russia a continuous process of distillation is employed, and it acts admirably with Russian oils, although little use has been made of the process elsewhere. The stills are placed in batteries, each still being mounted slightly lower than the preceding one, so that oil admitted to the upper can flow by gravitation through the whole series, the rate of flow being regulated by cocks between each still. This pretty process is thus well described in the "Encyclopædia Britannica":—"In the continuous process of distillation, instead of a single still with a progressive temperature, there is a series of retorts heated to successively higher temperatures which are carefully maintained, and the crude oil is caused to flow slowly and continuously through the whole series, being thus subjected to a steadily increasing heat, whilst the contents of each still remain practically constant. In this manner each still yields continuously a product of given volatility corresponding to the temperature at which it is maintained, and from the series of stills a range of products is continuously obtained corresponding to that yielded by the intermittent system within the same limits of temperature."

Some crude oils, of which Ohio, Canadian, and Texan are representative examples, are so charged with sulphur compounds that the distillates have to be specially treated to render the refined products saleable. Oxide of copper has been one of the most common chemicals used, and distillates

PLATE XIX.

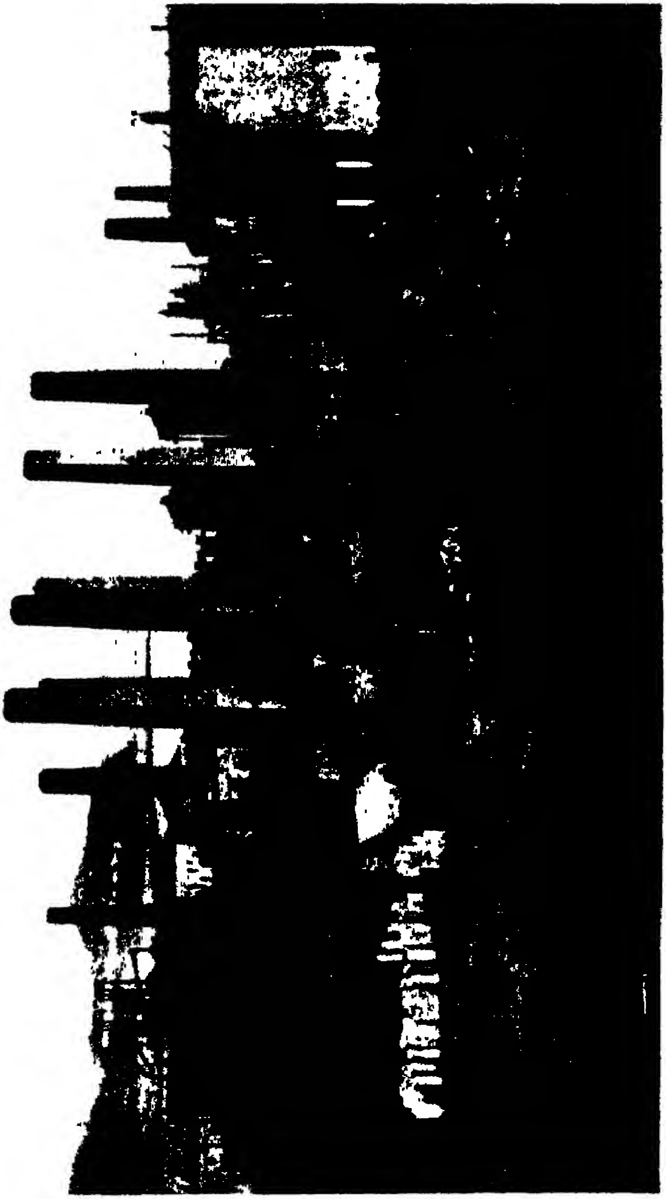

FIG. 32.—GENERAL VIEW OF BAKU REFINERY.

[To face page 158.

can be largely separated from the sulphur by passing the evolved gases over that substance. The copper unites with the sulphur, forming sulphide of copper, and copper oxide is re-formed by burning off the sulphur subsequently. Sulphur can also be abstracted by passing the vapours from the oil distillates over heated copper or iron turnings.

Most crude oils contain some sulphur, and when illuminating oil is prepared measures have to be taken for its removal if the quantity exceeds some .05 per cent. Some high grade oils contain as much as 1 per cent., and some Texan and Californian oils as much as 2 per cent., whilst in Mexico 4 per cent. of sulphur is not uncommon.

The solid paraffins when present in a crude oil concentrate during distillation in the residuum, which it is usual to treat after the benzine, illuminating and solar oils have been recovered, and their extraction is generally undertaken by reducing the temperature of the oil and passing the product under a high pressure through a filter press. The low temperature causes the solid paraffins to collect on the canvas sheets stretched throughout the filter press, and the oil runs away and is mixed with other distillates for redistillation, or for the preparation of lubricating oils requiring a low cold test. The crude wax collected in this way invariably contains a proportion of oil, the further removal of which is effected either by the application of great pressure to the wax enclosed in canvas bags, or by refiltration in the press, but even then a certain proportion remains which has to be extracted by a process called "sweating." Sweating is performed in a variety of ways whereby the oil is induced to separate from the wax in a melted state when spread in a film over water in shallow trays. The maintenance of paraffin wax at a high temperature facilitates the separation of the oils which are drawn off. By the careful adjustment of temperature it is possible in the same way to separate the paraffins with a high melting point from those with a low, the former being much more valuable than the latter.

Crude paraffin wax is often discoloured, and it is rendered white and translucent by treatment with animal or prussiate charcoal.

Refining.—Most distillates need a process of purification before they can be employed for domestic uses, otherwise the lamp oils do not burn freely and brilliantly, and the qualities of other products are generally inferior. The distillates contain a proportion of unsaturated hydrocarbons which are easily decomposed, and there are often sulphur compounds, oxygen, and other contaminating substances needing removal to raise the quality of the oil. Refining is almost universally accomplished with the aid of sulphuric acid and caustic soda, the former absorbing the more unsaturated and unstable constituents of the oil, the latter not only continuing further the process, but neutralising the acidity of the oils after treatment with acid. The oils are well agitated with sulphuric acid by mechanical agitators or by compressed air in a vertical cylindrical steel vessel, sometimes lined with lead to reduce corrosion, and after settlement the heavy sulphuric acid solution charged with thick tar is drawn off. During the agitation the treated oil decreases in density as a result of the abstraction of the denser and less saturated hydrocarbons which were attacked, but in warm climates especially the agitation has itself caused the evolution of many of the more volatile products of the oil, and so increased its density somewhat, counteracting the reverse effect of the acid treatment. The effect of refining upon the flash point is variable, some fractions, usually the lighter, having their flash point raised, others lowered by refining. The time of agitation and amount of acid used depends entirely upon the class of oil, the heavier oils always taking more acid and requiring longer agitation than the light oils.

Sometimes the distillates are treated several times in succession with acid, each application resulting in the abstraction of objectionable compounds and an improvement in

quality, but over-treatment with acid may cause the production of sulpho-compounds, which separate as a cloud from the oil after a long interval. In some cases it is customary to redistil the distillates after the first process of refining, fractionate, and again agitate with acid and soda. After treatment with acid the distillate is washed by a spray of water several times before introducing the caustic soda.

The caustic soda solution is agitated in the same way as the acid, and after settlement, withdrawal of sediment, and washing, the oils are ready for marketing.

It is estimated that only about 3 per cent. of the sulphuric acid added to the distillate for refining is actually used, and that 97 per cent. is added simply to secure contact of all the distillates with acid during agitation. Some 5 to 10 per cent. of heavy hydrocarbons are abstracted from the distillate by the acid, and these can be recovered by settlement, washing, and treatment with waste alkali, and can then be used as fuel or redistilled. In the shale oil works the waste sulphuric acid is used for treating the ammonia water for the production of sulphate of ammonia.

In the Baku refineries of South Russia each 100 tons of kerosene requires about 0.75 ton of sulphuric acid, and 0.25 ton of caustic soda under the worst conditions in winter.

In Pennsylvania from 4 to 10 lbs. of sulphuric acid are used per barrel of oil, equal to 32 to 80 lbs. per ton, and 1 lb. of caustic soda, equal to 8 lbs. per ton. Some 15 lbs. of Pittsburg coal are used per barrel for fuel, or 120 lbs. per ton.

Average Roumanian lamp oils require for refining 0.5 ton of sulphuric acid and 0.10 ton of caustic soda per ton.

Many other processes of refining have been introduced from time to time, but none has, hitherto, replaced to any important extent the original acid and soda treatment. A proportion of the dense unsaturated coloured hydrocarbons can be removed from crude oil by filtration or treatment with fuller's earth or charcoal, and Dr Edeleanou has patented a process of refining in which sulphur dioxide is the purifying

medium. It is claimed that the agitation of petroleum or petroleum distillate with liquid sulphur dioxide under pressure leads to the absorption of the dark, dense hydrocarbons which are chiefly responsible for the inferior quality of unrefined oils, and with this process of refining it is claimed that not only can the absorbed products be collected and used for other purposes, but that the sulphur dioxide can be recovered for use time after time. Powerful oxidising agents like permanganate of potash and ozone have been claimed to refine petroleum, and have received some attention from time to time, but on a commercial scale the processes have never met with much encouragement.

CHAPTER V.

SYSTEMS OF DRILLING OR BORING FOR PETROLEUM AND NATURAL GAS.

Drilling or Boring for Petroleum and Natural Gas—Selection of a Drilling Rig—Boring Records—Cable System of Drilling—Canadian Pole Tool Systems—Russian Freefall System—Galician System—Rotary and Flush Drills—Fishing for Lost Tools—Portable Drills—Shooting or Torpedoing Wells—Contract Drilling.

Drilling or Boring for Petroleum and Natural Gas.—The selection of a site for trial drilling in a new territory is decided by circumstances discussed on p. 89, and in Chapter II. is given a description of representative examples of the strata that may be encountered.

In oil-bearing series non-productive seams of strata are interspersed amidst petroleum-yielding beds, and in some cases considerable discretion is needed to decide when an oil-bearing stratum has been penetrated. This difficulty is particularly pronounced when water infiltrates into the well and obstructs any petroleum which might otherwise exude into the well, and also obscures the identity of the sand by washing away the contained oil.

Naturally, a definite test can always be made by giving the well a trial bailing with the bailer if there are misgivings concerning the worth of the indications, but this course is always delayed as long as possible in most formations, as the strata become disturbed by the removal of the liquid, and the walls of the well may collapse ("cave") and uncompact beds be set in motion by withdrawal of sand. The less material removed from the well when drilling, and the less the

strata are disturbed by bailing, the farther will each column of casing pass, and incautious attention to such details may lead to the enforced reduction in size of casing until the limit of diminution is reached long before the required depth is attained.

Usually an escape of gas and the steady accumulation of oil in the well will indicate the proximity of an oil source, but drilling should only be suspended for a trial bailing or pumping after continuing some distance into the oil-bearing beds. In several cases the author has personally instructed a trial bailing to be made when there was only water in the well and no indication of petroleum, being guided solely by the character of the sands raised and the knowledge that an oil-bearing horizon had been reached. In one such example, where water only was bailed for a week before being overcome, as much as 150 tons of oil daily were obtained, and in another instance where water which filled the well was subsequently excluded by a cementation, a production of 500 tons daily was obtained for a while, and in two years the well yielded 140,000 tons of oil, although no indications of petroleum had been observed. The rate of drilling varies greatly. In oil-fields where the strata do not "cave" and the wells are of small diameters, the average rate of drilling may reach 50 to 150 feet daily with a cable rig, but where the strata are much disturbed or steeply inclined and "caving" is constant, the rate does not often exceed 6 to 10 feet daily.

Where the strata are compact and several oil sources of limited capacity have been passed, it is a common practice to insert the last column of casing with perforations at the depths where the oil shows occurred, the outer larger casings being removed to permit these sources to supplement the main supply, if not required for the exclusion of water. Indications of petroleum during drilling are often described as "oil shows" or "pay streaks."

Selection of a Drilling Rig.—The choice of a suitable

drilling rig to operate in a new district should only be made when some idea of the geological character of the strata has been ascertained, but often very little information is procurable from surface exposures in virgin territories, and a system is chosen with which the interested persons are most familiar. In most oil-fields modifications of some recognised system become generally adopted when the peculiarities of the region are fully understood, and the pioneers in new territories have usually to contend with special local difficulties which for a time retard progress. A few general rules may be laid down as a guide to the selection of a system, but the local physical conditions have to be considered somewhat, as the absence or scarcity of water precludes the employment of water flush systems and all rotary processes where much water is required.

If there is much hard rock to penetrate, either a heavy cable rig or one of the rotary systems using chilled shot can be employed with advantage. Diamond drilling is very rarely employed for petroleum exploration on account of the great cost of such large diamond crowns as are necessary for wells of 10 inches and upwards in diameter. For general prospecting in a new field, where little or nothing is known of the geological strata, the Canadian system is one of the safest to adopt, for although the rate of drilling is not very great, except in suitable formations, the plant enables strata of nearly all kinds to be penetrated, and requires less skilled attention than many other forms of drill.

Where the strata are known to consist principally of limestones or sandstones of moderate hardness, a cable rig should be chosen, as the heavy vibration causes constant fracture of pole tools when they are used. When the rock is known to be exceedingly hard, either specially heavy cable tools should be chosen, or, in the event of plenty of water being available, a chilled shot rotary plant, as ordinary steel cutters on rotary plants are not suitable for excessively hard sandstones or calcareous sandstones such as are sometimes met with.

In clay shales, interspersed with beds of sand, either the cable or Canadian systems can be operated, but if the strata are inclined at a steep angle or considerably broken up, special provision must be made to deal with "caving." Whilst horizontally disposed or only slightly inclined clay shales and sandy-clay shales will often hold up well during drilling, and allow several hundred feet to be drilled without lining, at times only a few feet can be passed before continued caving prevents the free working of the tools and makes casing necessary. In such ground it is often necessary to under-ream with an under-reamer or eccentric bit, and keep the column of casing near to the bottom of the well. The speed of drilling also has a considerable influence on the depth that can be drilled without supporting the well, and in soft formations the fewer the stoppages whilst working in an "open" (uncased) hole the deeper will it be possible to proceed without inserting casing.

Where considerable thicknesses of loose, running sands are known to occur, it is absolutely necessary to employ one of the flushing systems. Small beds of flowing sands or gravel can be dealt with generally with any of the ordinary boring plants, by driving the casing through and past the troublesome stratum, but where, as in Texas and Louisiana, considerable thicknesses of loose water-bearing beds have to be penetrated before the oil is reached, a water flush is really the only practicable method. In pioneering work a combined cable and water flush system is sometimes used.

The great advantage of a core-extracting plant over a percussion system in exploration work is obvious, nevertheless in few cases is it advisable or even feasible to employ other than percussion systems on account of their greater simplicity, cheapness, and adaptability to deal with all classes of strata which appear.

The percussion system of drilling has the distinct disadvantage of so pulverising and mixing the strata in which the drill works that the identity of the beds passed can often

only be surmised. Alternate beds of clay and sand cannot be recognised as such, and thin seams of distinctive material become so intermingled that they entirely escape recognition unless the debris is minutely examined. Intelligent observations by an experienced driller will enable a fairly accurate record to be kept, as he will be able to distinguish by the action of the drill when he has passed from one stratum to another. The determination of the strata passed is facilitated by a knowledge of the relative speed of drilling at different depths. Amidst the detritus raised after drilling a few feet, there are generally fragments of the harder material of sufficient size to indicate their character *in situ*, but little attention is usually bestowed on such details, and the operator simply records the predominating material raised in the bailers and sand pumps.

Boring Records.—Whether prospecting in a new oil-field or exploiting an old one, complete and, as nearly as possible, accurate records of the borings should be kept. In some countries legislation enforces the compilation of drilling returns for official reference, but whether this is compulsory or not daily journals of all boring wells should be preserved. The geological information afforded by the early borings in a new district is of immense importance in deciding upon the direction in which future operations shall extend, and not only should the geological data be compiled, but a full history of the drilling should be given in order that subsequent operators who have not had the early experience may realise the difficulties encountered in passing through the different beds.

A full boring journal should be divided into a drilling and a geological section. In the former should be stated the time worked, number of feet drilled, the length, duration, and cause of any delays or stoppages, and any special remark which would indicate the cause of slow drilling or loss or breakage of tools. Full particulars should also be given

concerning the size, thickness, and kind of casing or lining tubes inserted or withdrawn, and notes should be made as to its freedom or tightness. In the geological return the depth should be given at which every change of stratum occurs, and as full a description of each stratum as possible; any change of level of liquid, if any, in the well should be recorded and the presence and character of water, petroleum, or gas should be fully reported.

The importance of correct data can only be appreciated by those closely allied with oil-field development, as in cases where unexcluded surface water fills the well, an appearance of certain kinds of sand or the escape of a little gas is sufficient to indicate the possible presence of an oil source and decide a definite course of action.

In compiling boring journals of percussion drilled wells the following hints may prove useful. Clays should be prefixed by their colour or shade in a hydrous condition as raised from the well. If of a particularly stiff constitution they should be so described, and if they "cave" a great deal and show a flaky structure they can be described as clay shales. A mixture of clay and sand in which the former predominates should be described as sandy clay or sandy-clay shale if there is no reasonable cause to believe the sand is from an upper source or in separate laminæ.

Sand and sandstones can generally be distinguished by the vibration caused by the blow during drilling, and by particles of the rock which are almost invariably raised with the sludge when it is the latter. The colour should be noted, and they should be differentiated by the fineness or coarseness of the grains, or described respectively as grits, gravels, or conglomerates if the particles are sharp, rounded, or cemented together. If much lime is present a sandstone should be described as calcareous, or if impregnated with iron a stratum should be termed ferruginous.

Sands should be classified as *"water" or "running" sands* if they contain water (the latter term being confined to those

BORING RETURNS.

Commenced.......................... *Completed*.......................

Well No...............

Section or Plot No...............

Date.	Amount bored	Total Depth of Boring.	REMARKS. *N.B.*—State here the cause and duration of any delays or stoppages, and give full particulars of any auxiliary work such as fishing for lost tools, repairing casing, cementing, trial bailing, &c.	Casing. Lowered. Size, Thickness, and Quantity.	Casing. Lowered. Total Depth of Casing.	Casing. Removed. Size, Thickness, and Quantity.	Casing. Removed. Total Amount Removed.

Signature of Manager...............................

Date...............................

GEOLOGICAL REPORT.

Description of Strata.	Depth at which Stratum was Penetrated.	Level and Nature of Liquid in Well.	Specific Gravity of Oil, or Salinity of Water in Well.	REMARKS. *N.B.*—State here any peculiarities which may manifest themselves. Indicate hardness or caving character of strata and presence of gas, water, or oil. Any change in level or character of liquid in well should be notified in Column 3, and more fully described here.

Signature of Manager...............................

Date...............................

which rise in the casing and fill up the well as fast as removed), as *gas sands* if they contain gas but no oil, and as *oil or bituminous sands* if they contain petroleum, or solid or semi-solid petroleum-like products.

Limestone or marls are generally recognised by the colour of the sludge, but can always be definitely distinguished

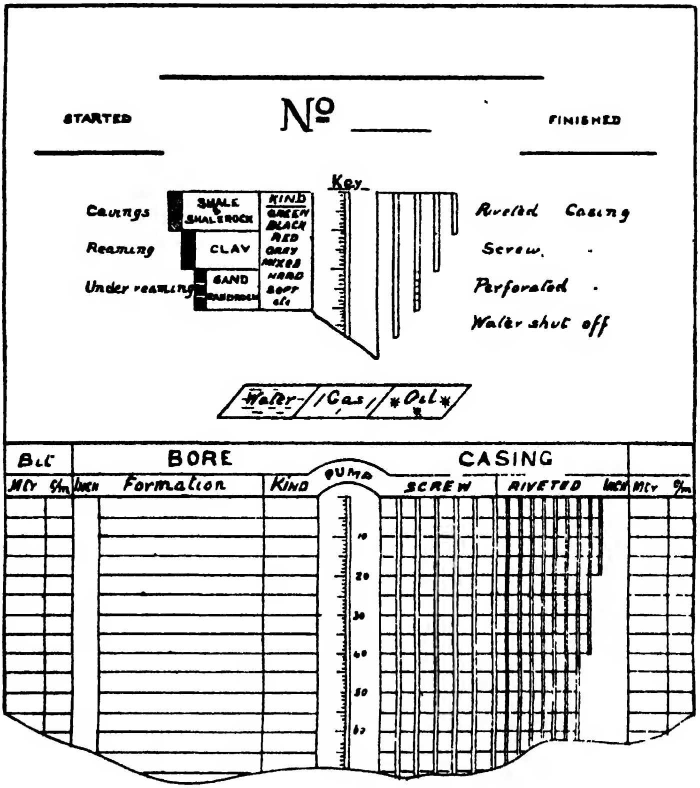

FIG. 33.—FORM OF BORING RETURN USED IN GALICIA.

by the addition of a little dilute hydrochloric acid, when a brisk effervescence ensues, and the material dissolves with evolution of carbon dioxide.

On p. 169 is an example of a Boring Return used by a number of companies with which the author is professionally

associated. The form was prepared to cover general prospecting and development, and has been found sufficiently complete for most purposes, although in some fields where exceptional conditions exist a modified return is sometimes used. The drillers send in a single form each day, and the information is then transcribed into a foolscap size book of printed forms kept for the purpose in the office. When companies send home drilling returns from abroad, it is usual to have forms of sufficient size to show either seven, fifteen, or thirty-one days' work according to the frequency with which the mails leave or the returns are required.

Fig. 33 illustrates a form of Boring Return, designed by Mr Geo. von Kaufmann, and largely used in Galicia by the oil producers.

The United States Geological Survey issued some very excellent instructions for the preparation of well records in the "Record of Deep Well Boring for 1904," which should be read by those interested in the question.

Cable System of Drilling—*Rig.*—One of the most popular and best known systems of drilling is that commonly designated as the American or cable system in which a flexible manilla cable of special construction is used. The drilling is performed by a heavy string of tools suspended from the cable to which a reciprocating motion is imparted by its suspension from an oscillating "walking beam." The derrick for a full-sized rig is of the usual type, 64 to 82 feet high with 16 to 20 feet base, and at the summit are two pulleys, known as the crown pulley and sand line pulley, whose spindles rotate in bearings. To one side of the derrick is erected on heavy foundation timbers a strong vertical upright (samson post), upon the top of which is a bracket on which the walking beam is pivoted. One end of the walking beam immediately overlies the mouth of the well when horizontal and the other end is directly above a crank attached to the band wheel shaft. This shaft receives the

drive on a 10 feet diameter by 12 inches wide wooden band wheel by belting from an engine, and motion is transmitted to the walking beam by a connecting rod "pitman," the lower end of which slides over the crankpin when oscillating motion is required. When the pitman is disconnected from the crank the band wheel shaft runs idle, but by means of a lever a small sand-line drum (sand reel) running in bearings behind the main shaft can be drawn forward so that the rim of the bandwheel engages with a friction pulley attached to the drum shaft. The sand-line drums vary from 6 to 20 inches in diameter, the larger sizes being only suitable for shallow wells, as the friction drive is not sufficiently powerful to raise bailers from a great depth with the larger sizes. A 10-inch drum is usual for a 1,500 feet well, and it is customary to use a double sand reel, half of which is separated by a disc so that the spare rope can be coiled upon the one drum and only transferred to the other as the well gets deeper. The sand-line drum is thus given a rapid rate of rotation when brought into action, and it serves to operate the sand pumps or cleaning tools employed for removing the pulverised debris from the well after drilling.

At the opposite side of the derrick to the walking beam are mounted the "bull wheels," which consist of two wheels 7 to 8 feet diameter, built up of oak arms with pine cants to form a rim attached to the extremities of a bull-wheel shaft 16 inches diameter. One of these wheels has in the centre of its rim a V groove, formed of oak cants, to carry the "bull rope" which drives into a grooved "tug" wheel 7 to 8 feet diameter attached to the side of the band wheel. The "bull rope" is crossed, and generally two V grooves are constructed to enable a double drive to be obtained when the weight is heavy. Upon the "bull wheel" shaft is coiled the drilling cable preparatory for working, one end being tied to the arms of the bull wheel whilst the other is led over the "crown" pulley at the top of derrick and attached to the tools. Both the bull wheels on the bull shaft are fitted with handles enabling the

shaft to be rotated by hand, and the one removed from the driving side is fitted with a powerful band brake that enables the tools to be lowered slowly into the well by gravitation and held in position when the driving rope is disconnected from the tug wheel.

In the Californian rig a "calf" wheel very similar to the bull wheel is placed in the derrick on the engine side and driven when necessary by a rope from an iron pulley keyed to the band wheel shaft. This "calf" wheel is used for working the pulley blocks that manipulate the casing, as the Californian strata make it necessary to constantly keep the casing in motion. Even when it is unnecessary to keep the casing in motion the "calf" wheel fulfils a useful purpose for handling casing, as in its absence it is necessary to take down the tools, remove the cable from the bull-wheel shaft, and coil on the casing line before the casing can be inserted, all of which operations have to be repeated in the reverse order before drilling can be restarted.

The operation of sinking a well is generally commenced by the insertion of a "conductor" from 12 to 30 feet long, taking the form of a wooden cylinder built up of strips of wood 2 inches by 4 inches, chamfered longitudinally on the sides and bound together with hoop-iron straps nailed to the wood at intervals of every 3 or 4 feet. The conductor serves to truly guide the casing, great care being necessary to secure the absolute verticality of the conductor.

Spudding.—Drilling operations cannot be conducted with the aid of the walking beam until a depth of about 100 feet is reached to enable the string of tools to be lowered into the well and connected with the walking beam, consequently a start is made by what is termed "spudding." A bit, auger stem, and rope socket are alone used for "spudding," and these are lowered by the bull wheel into the well which has been carried to a depth of 20 or 30 feet in the manner described above. When the bit is lowered to the bottom a certain amount of slack cable is let out, a short rope with a "spudding

shoe" is connected to the cable near the bull wheel, and a small grooved roller to slide over the crank is put into position. At each revolution of the crank the cable is alternately drawn forward and released, the tools being thus raised and allowed to fall by gravity, and as the drilling proceeds additional rope is released from the bull wheel until the tools are raised for cleaning out the pulverised debris. When drilling proper is commenced the full string of tools, consisting of chisel or bit, auger stem, jars, sinker bar, and rope socket, are attached to the temper screw and suspended from the walking beam after being lowered into the well. Fig. 34 shows the operation of spudding.

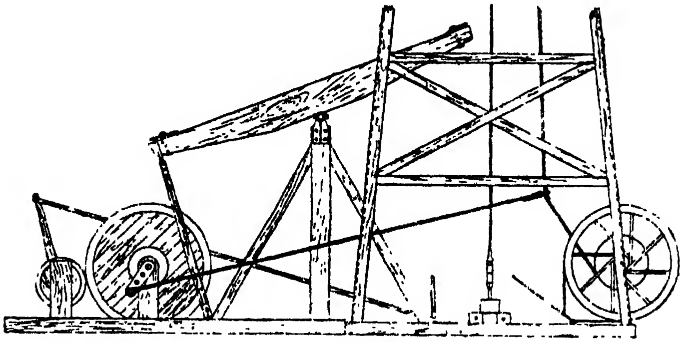

FIG. 34.—METHOD OF SPUDDING AND DRIVING CASING.

When driving casing, drive clamps are bolted to the stem below the joint with the rope socket.

Drilling Bits.—There are several varieties of drilling bits which, though differing but slightly in design, nevertheless find their respective advocates. They are preferably composed of a forged Lowmoor iron block, to which is welded a high grade steel end, making a total length of from 4 to 6 feet; but bits composed entirely of steel, except the shank, can be purchased, although they are very expensive, and many confine themselves to the purchase of bits with about one-third of their length of high grade steel. The ordinary pattern of bit is shown in Fig. 36, whilst a very popular pattern is the Mother Hubbard, illustrated also. It is claimed that the

square edges of the latter type of bit constitute an advantage in caving ground owing to the greater ease with which it can be jarred loose, compared with the ordinary pattern, which forms a wedge. Below the threads there is a depth of several inches turned circular to allow for occasional rethreading, and

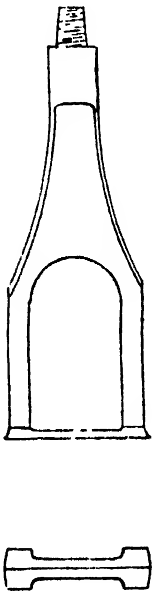

FIG. 35.—SPUDDING BIT.

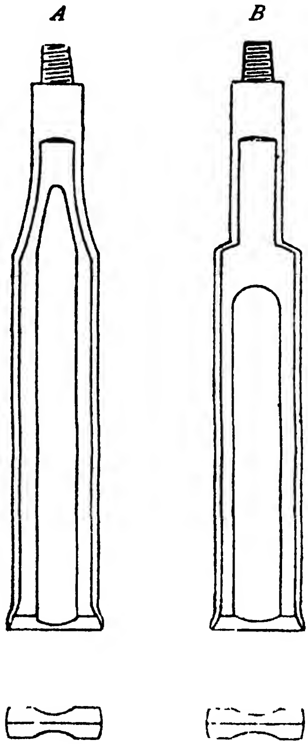

FIG. 36.—DRILLING BITS OR CHISELS.
A. Californian Type.
B. Mother Hubbard Type.

below this is a flattened portion upon which the wrenches are placed when screwing up or unscrewing the joints. The spudding bits, which are only used for the first few feet in each well, are only about 3 feet long, and have less steel, owing to the light work they are called upon to perform. There are in general use in the American oil-fields several standard patterns

of threads in common use, and it is advisable to make a careful distinction of what is employed in order to avoid difficulties when ordering spares. The old I and H joint is largely specified, but the so-called standard joint is also in common employment, as well as the gauges of private manufacturers.

Auger Stem and Sinker Bars.—Auger stems and

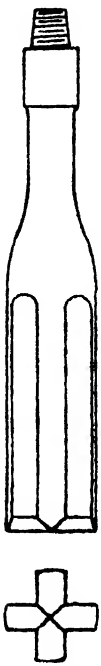

FIG. 37.—STAR BIT.

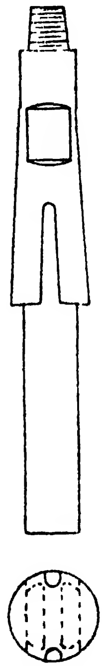

FIG. 38.—DOUBLE REAMER.

Used for rounding-up or reaming bore-hole.

sinker bars are simply bars of round iron or mild steel from 6 to 45 feet long, at one end of which is welded a screwed "pin" joint with squares for wrenches, and at the other end a "box" joint with similar squares. In all cases sufficient metal is left above the squares to permit occasional rescrewing. The auger stems, which keep the drill vertical and give the hitting blow to the bit, vary from 16 to 45 feet, and from $2\frac{3}{4}$

inches to 5¾ inches in diameter. The heavier sizes are used for drilling in hard formations where an extremely hard blow is necessary. For general practice the auger stems can be confined to 4 or 4½ inches in diameter, and 25 to 30 feet long, and the sinker bars of the same diameter but 10 feet long.

The screwed joints on American tools are always tapered, so that they screw up by hand to about $\frac{1}{16}$ inch of the neck, when they require pulling up to butt with wrenches. The table below shows the sizes of joint recommended by the Oil Well Supply Company of Pittsburg, each joint being made in four designs, viz., 7 or 8 threads sharp; 7 threads flat; the sharp threads being ordinary V's; the flat threads have the tips and base flattened slightly.

SIZES OF TAPER SCREWED JOINTS FOR CABLE TOOLS.
(All in 7 Flat Threads or 8 Sharp Threads per Inch.)

Size of Hole.	Size of Joint.	Size of Wrench Square.	Diameter of Pin Collar.	Diameter of Box Collar.
Inches.	Inches.	Inches	Inches.	Inches.
3½ or 4	1⅜ × 2	2¼	2⅞	3
4¼ or 4½	1⅝ × 2½	2½	3¼	3⅝
5	2 × 3	3¼	4¼	4⅜
5⅝	2¼ × 3¼	3½	4½	4¾
6¼	2⅜ × 3½	4	5	5⅜
6¼ or 6⅝	2¾ × 3¾	4	5¼	5⅝
7⅝ or 8¼	3 × 4	4½	6	6¼
8 or larger	3¼ × 4¼	5	6¼	6⅝
8 or larger	3½ × 4½	5	6½	6⅞
8 or larger	4 × 5	5½	7	7⅜

The author usually specifies a 2¾ by 3¾ inch joint with 7 flat threads per inch for all sizes from 6 inches and above, unless very hard ground is suspected, when the tool joints below the jars may with advantage be increased to 3¼ by 4¼ inches for 8-inch hole and above. The flat threads are less liable to damage than the sharp threads, but in any case the joints must always be protected by "thread protectors" when not in use. When a plant is sent abroad a set of box and

pin templates should always be included to act as a gauge when rescrewing damaged joints, and it is good practice to include a spare pair of joints for rewelding on to a broken or damaged bit or stem should there not be local provision for rescrewing.

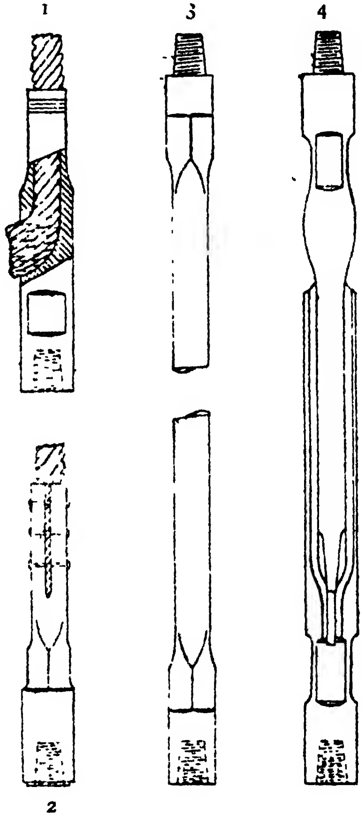

FIG. 39.—AMERICAN CABLE TOOLS.

1. New Era Rope Socket.
2. Ordinary Rope Socket.
3. Sinker Bar or Auger Stem.
4. Jars.

Jars.—The drilling jars are two steel links forged from one solid piece, carefully made to slide one inside the other for a distance of about 6 inches (see Fig. 39). The jars play the most important part in the working of the tools, for without their use the cable could not be used in soft strata. If

the bit became wedged in the hole, either through cavings of overhead material or through the immersion of the bit into a sticky clay, no direct pull on the cable would ever cause its liberation; but with the jars, connected as they are to a sinker bar weighing often 600 lbs., their release is secured by a succession of powerful upward blows administered to the links by slightly slackening the cable and running the walking beam. When drilling in a hard formation the jars are rarely brought into action, the blows being delivered to the stratum at the extreme elastic limit of the cable when running at a constant speed, the intensity of the striking blow varying with the number of oscillations of the walking beam.

Fishing jars are generally made stronger, and given a 12-inch to 3-feet stroke, so that a much harder blow can be imparted to fishing tools when a firm hold has been secured of the lost tools.

Rope Socket.—A rope socket is used for coupling the cable to the string of tools. The common wing form is simply a screwed end provided with square for wrenches, from which extends two semicircular strips, between which the end of the cable can be placed. When the cable is inserted in position a succession of iron rivets is driven through holes in the wings and the cable, and riveted up on the outer edges.

An improved form of rope socket is the "New Era," which consists, as before, of an internally screwed end for connection to other tools, but in place of two wings has a turned portion internally bored to admit the cable freely. To one side, and near the base of the bored portion, is a well-rounded taper orifice inclined upwards, through which the end of the cable can be drawn after insertion into the socket. An exceedingly tight connection is made by plaiting additional strands of hemp into the free end of the rope after passing through the side orifice, and then drawing the cable back so that the plaited portion fills the taper orifice. There are other designs of rope socket, but the two above named are the most generally used for manilla cable drilling.

Manilla Drilling Cables.—The usual sizes of cables in use are 2 to 2½ inches in diameter. They are hawser laid and made of fine grade manilla in long fibres twisted specially hard to withstand the severe strain they have to sustain. The three strands are tightly twisted in the reverse direction to the twist of the cable itself, so that when subjected to extreme tension by the weight of the tools the cable does not unwind. The twist is so arranged that the fibres of the strands run parallel with the rope, and not at an angle with its length, otherwise they would more quickly wear by abrasion against the sides of the well or casing during drilling. The twisting must be perfectly regular, otherwise the strands slacken and all the weight is thrown on a single strand. Drilling cables usually stretch about 50 per cent. of their length, so that a 1,500 feet cable will generally pull out to over 2,000 feet owing to the great strain thrown upon it during drilling.

The wear and tear of cables is always excessive, but their lives vary in different oil-fields, and depend upon the weight of tools and rate of progress. In Pennsylvania and West Virginia 1 to 2 feet of cable are used per foot of drilling, and in moderate ground with medium weight tools about 1 foot of drilling can be performed per foot of cable, which, with a 2¼ inch cable, works out to approximately eightpence a foot.

Drilling.—Before lowering the string of tools into the well they are screwed together with such force that no blows in the well can cause their detachment. This is accomplished by means of massive wrenches, at the extremities of which is applied great pressure with the aid of an "oil-well jack," whereby extreme leverage is obtained. The "jack" in general use is that known as the "Barrett" (Fig. 40), and it consists of a semicircular toothed rack which is bolted to the derrick floor, at one end of which the stationary wrench rests against a projection, and on which a traveller is caused to move forward operated by a lever to force the second wrench along. Before screwing up the joints the threads should be thoroughly cleaned, all oil removed, and then washed with water; and

care should be taken to ascertain that the joints butt. The tools are then lowered from the bull shaft by releasing the brake until near the bottom, when the cable is gripped by a pair of clamps attached to the temper screw slung from the end of the walking beam. Fig. 40 shows the process of screwing up the joints.

The temper screw is illustrated in Fig. 41, and consists simply of a square-threaded screw working in a split nut which can be tightened by a clamp. It enables the cable to be fed out slowly as demanded, and also rotated if desired. The "pitman" is connected to the crankpin before the

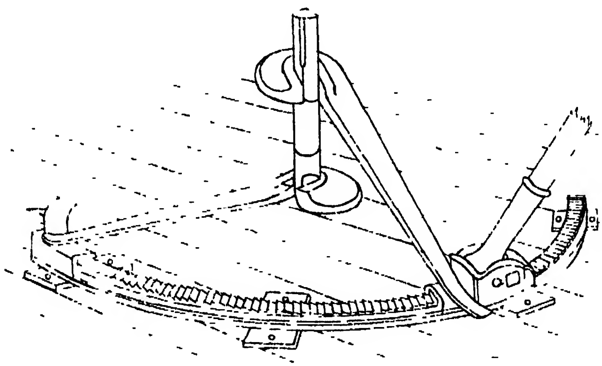

FIG. 40.—METHOD OF TIGHTENING UP JOINTS OF DRILLING TOOLS WITH OILWELL "JACK."

temper screw clamp is connected, and about 20 feet of cable is run loosely off the bull shaft. When the beam is put in motion the temper screw is fed out by the operator until the bit can be felt to strike the stratum, and as the blows decrease in intensity the screw is fed down.

The strokes at which the drill can be worked depend upon (1) the nature of the stratum; (2) the quantity of liquid in the well; (3) the diameter of the well. Some material quickly forms a stiff puddle after drilling a few feet, which prevents the bit from sinking freely, whilst in other cases the pulverised material mixes freely with the water in the well and allows

many feet to be drilled before cleaning out. The number of strokes varies from twenty to forty a minute, and if no liquid is present water must be periodically put down the well to allow the formation of a puddle. During drilling it is necessary for the bit to rotate in order to form a round hole and not strike repeatedly in one place, and it is customary to twist the rope a fraction of a turn at each stroke until several coils of rope are coiled around the temper screw, when they are uncoiled again. The necessity for thus twisting the rope is doubtful, as the alternate application of tension and relaxation of the strain as the tools are in turn raised and rest on the base of the well causes them to spin at each stroke, and it is very unlikely that the same spot would be struck twice in succession. When drilling in inclined strata great care is needed to prevent the bit running out of vertical when it strikes a hard formation after passing a soft stratum, as in Fig. 42. Many drillers now insist that no advantage is gained by rotating the cable, partly because it is not found to be necessary in practice, and, secondly, because it is certain that in many cases the few twists given to the short length of rope between the temper screw and the overhead pulley can have little effect upon the tools at a depth of 1,000 feet or more, unless the rope becomes so rigid as a consequence of the weight that it partakes of the character of a rod.

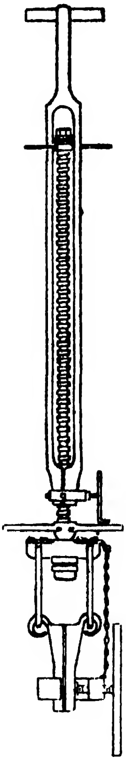

FIG. 41.—TEMPER SCREW.

When the bit does not fall freely and deliver a hard blow the engine is slowed down, the bull rope is slipped on to the pulley, and the engine is stopped just as the slack rope is all taken up between the bull shaft and the temper screw. The temper screw is slacked out, throwing the weight of tools on

the bull shaft, the pitman is disconnected from the crank-shaft, and on readmitting steam to the engine the tools are raised to the surface, the bull rope being thrown off by striking gear, and the brake applied just as the bit emerges from the hole. The tools are then allowed to rest suspended and tied to one side of the derrick, the band brake preventing their descent until ready for lowering in the well.

When drilling in a clean hole the number of strokes can be accelerated, and a long stroke and hard blow results, owing to the spring imparted to the rope, but as a thick puddle is formed and the blow diminishes in intensity the speed must be reduced to enable the tools to deliver a blow. Fig. 50 shows a modern cable rig of the Californian type.

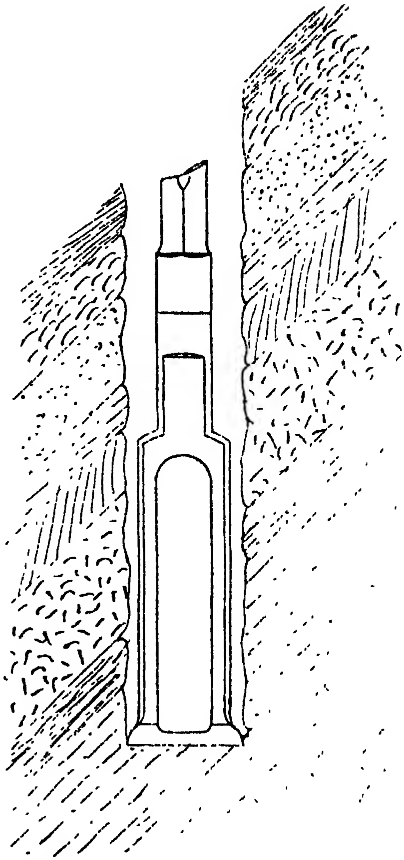

FIG. 42.—BIT WORKING IN INCLINED STRATA.

Showing how a drill can easily run out of vertical in inclined strata where it strikes a hard rock beneath a soft stratum.

Dressing Bits. — If the bit requires "dressing" it is disconnected and trimmed in a forge in the derrick if there is no gas or oil about, or at a distance if it is unsafe in the derrick. The bits are given only the faintest approach to a point, the cutting edge being almost

flat and taking the form of a rammer. After a period of working, or even a two or three hours' run in hard sandstone, the bit becomes worn and is diminished in width, and a smaller hole is drilled unless the bit is heated and hammered out to the desired width. A large forge is required for heating the larger sized bits, and now an up-to-date plant is provided with a small turbine blower for the draught. When a bellows is used the drillers generally attach a cord between the arm of the bellows and the crankpin, and deflect the direction of motion by sheave blocks, thus saving hand power. The cutting edge of the drill is hardened by quenching in water and tempering after the dressing is completed. When bit dressing is performed in the derrick a great saving can be effected by using a derrick crane with chain hoist and swivel tool wrench, which is also of immense service for attaching bits to the auger stems after dressing.

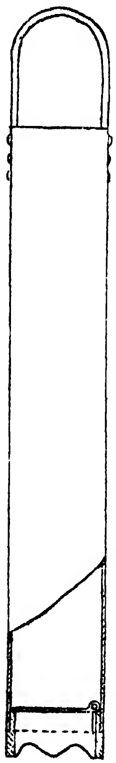

FIG. 43.—COMMON CONDUCTOR BAILER.

Cleaning Out Hole. — The pulverised debris made by the drill is removed from the well by sand pumps or bailers. The cleaning instruments are lowered on a $\frac{1}{2}$-inch to $\frac{5}{8}$-inch diameter wire rope from the sand reel, which is rotated by a friction wheel being brought in contact with the band wheel rim. The bailers are lowered into the well by gravitation, the speed being regulated by forcing back the friction wheel against a wooden stop. If the pulverised stratum is chiefly clay or sandy clay, it can generally be cleaned out with a plain bailer, simply a cylindrical vessel a few inches less in diameter than the well with a valve opening inwards at the bottom. The "conductor" bailers of from 7 to 11 inches in diameter are

from 3 to 5 feet long, but when the diameter of the well is small, the length of bailer is increased to 20 and 30 feet long in order to remove more debris at each descent.

When the pulverised debris is very thick or largely composed of sand, it is necessary to use a sand pump, which

FIG. 44.—COMMON BAILER.

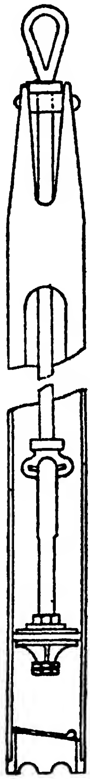

FIG. 45.—"CHICKERING" SAND PUMP.

FIG. 46.—"MODEL" SAND PUMP.

is a cylindrical vessel with a lower valve as before, but inside is a piston, which, on raising, causes the mud to rush in and fill the vacuum caused. There are many forms of these sand pumps.

Sand pumps are generally provided with some form

of irregular or pointed steel point, which causes it to sink into the sand when allowed to descend rapidly to the bottom, the piston then drawing more material into the chamber above the valve. Amongst special American sand pumps may be favourably mentioned the "Chickering" and "Model." Various bailers and sand pumps are illustrated in Figs. 44-46.

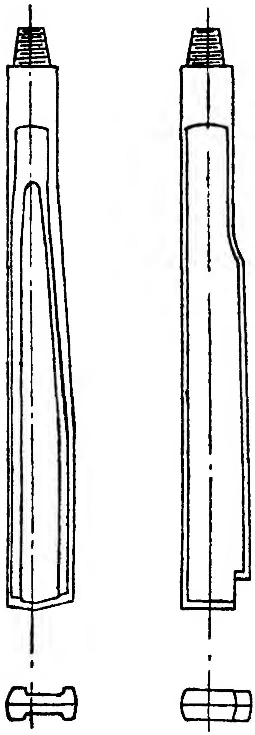

FIG. 47.—UNDER-REAMING OR ECCENTRIC BITS.

Under-reaming.—The cable system is not well adapted for under-reaming, but it is necessary and practicable in some cases. The usual process is to drill as far as possible without lining the hole, after which the well may be lined, and a reduced size of hole continued, or drilling may be continued with smaller tools, and the casing driven by "monkeys" as the work progresses. When the ground is caving, and it is desired to proceed deeper without reducing the size of casing, it is necessary to use under-reamers if the ground is too hard for the casing to be driven past. The excellent Russian under-reamer, Fig. 55, is only applicable to wells of large diameter, but there are several forms in which the under-reaming cutters are kept extended by internally placed springs. An eccentric bit is sometimes used for under cutting, but its action is not reliable in all classes of ground. The eccentric bit, Fig. 47, is a chisel in which the cutting edge, instead of being horizontal, is tapered slightly towards the edges, from a point not corresponding with the centre of the bit, but an inch or two to one side. It is claimed that, as in the case of an eccentrically sharpened drill, the bit

will rotate upon the point, causing the formation of a hole equal in diameter to the longer radius. The Austrian under-reamer illustrated in Fig. 48 is a favoured form, but there are other types equally effective.

Fishing Tools.—The most common accidents in cable drilling are the following:—Breakage of cable, unscrewing of tools, fracture of one of the joints either immediately at the base of the threads or at a weld, sticking of tools through cavings or rising plug. If a cable breaks, a new string of tools is prepared, consisting of rope socket, sinker bar, fishing jars, and a rope "spear" or "grab." The former is simply an iron rod, from which protrude a succession of upstanding spikes, whilst the latter has two or three prongs or wings, between which there are a number of upturned spikes. If either of these is allowed to fall heavily into the midst of the tangled cable in the well, it rarely fails to secure a firm grip, and the tools can be withdrawn. If during the period of loss the tools have become firmly embedded in the settled debris, it will be necessary to use the jars and possibly jar off the lost rope in pieces, until the top of the rope socket is reached. For the purpose of extracting short ends of rope remaining after the grabs have been used, an instrument called a "mouse trap" is frequently used, consisting of a cylinder, about 2 to 3 feet long, fitted with a flap valve on the bottom with its edges sharpened, so that on lowering the instrument passes over the rope, and on being raised the valve closes and cuts the gripped rope. A form of "slip socket," an arrangement with bell mouth to guide over the tool is then lowered, which allows two slips to automatically catch on the

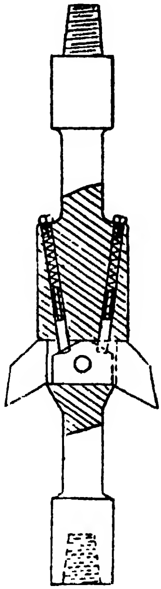

FIG. 48.—AUSTRIAN UNDER-REAMER.

edges of the squares used for screwing up (see p. 221). By jarring upwards (that is by loosening the rope until the upper link strikes a hard blow at the top of the lower when the walking beam is put in motion after "hitching" on) the string of tools is freed and raised. If this latter operation

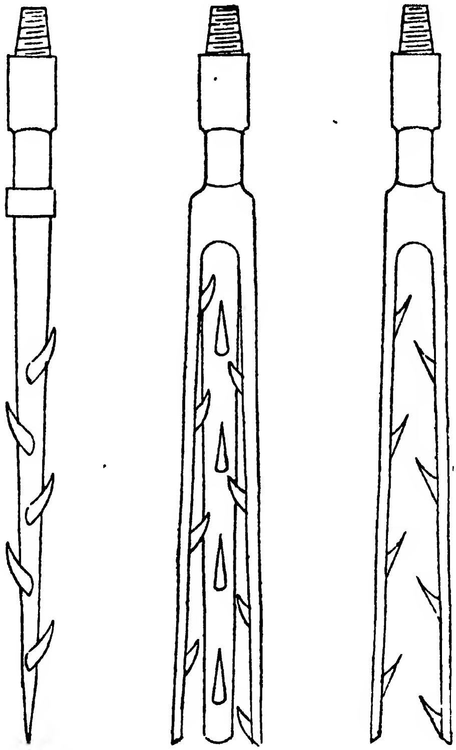

FIG. 49.—ROPE SPEARS AND GRABS.

fails, the recovery of the tools is a difficult problem, and it may be necessary to try washing out the well with water, or lowering fishing tools on a string of casing and jacking with hydraulic jacks. Fig. 49 shows the rope, spear, and grab.

If the tools become unscrewed, they can usually be raised at once by lowering either a "horn socket," or the above-

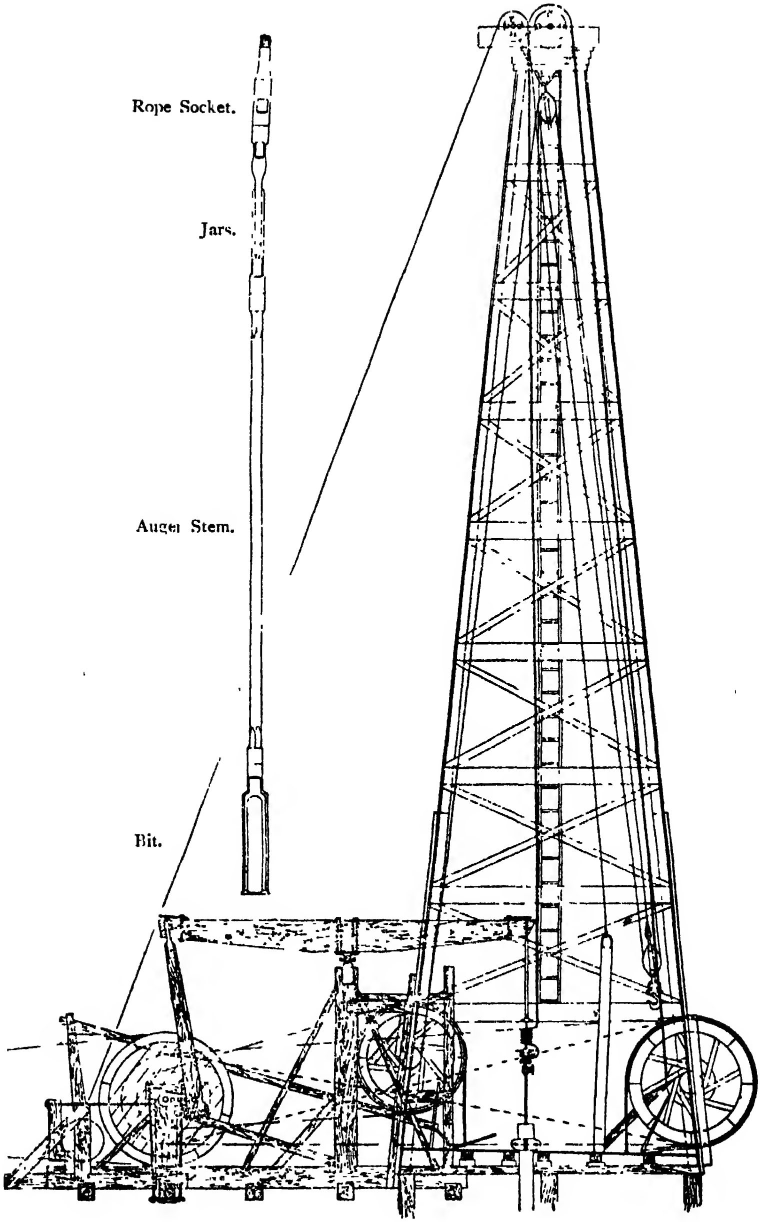

FIG. 50.—CALIFORNIAN TYPE CABLE RIG.

Showing string of tools at side. The driving ropes are always crossed in practice.

named "slip socket" (see Figs. 61 and 66), the former being simply an internally tapered tube with a removable bonnet, which guides it over the lost tool to take a friction hold. If the tools become so firmly held during drilling that they cannot be jarred loose with the drilling jars, a rope knife is lowered to a point immediately above the rope socket, and the cable is cut, the above-described operations with the slip socket, &c., being repeated. There are many forms of rope cutters worked either on the sand line or on a string of tubes or sucker rods. Usually a set of small jars is included to enable a succession of blows to be administered to the knife.

There is a great variety of special fishing tools for particular duties, but fuller details of fishing generally are given under that heading. When a specially difficult fishing operation is suspected, it is preferable to abandon the cable entirely, and use a string of rods or heavy tubes, to which the fishing tools can be attached.

Specification of Complete Cable Rig and Tools for Drilling to a Depth of 2,000 Feet with 12½, 10, 8¼, 6⅝, 5$\frac{3}{16}$ Inch Internal Diameter Collared Casing.

1 steam boiler capable of evaporating with ease 1,500 lbs. of steam per hour at 100 lbs. pressure with fuel found in the district, fitted with feed pump, injector, and spares.
1 horizontal 11 by 12 inches single cylinder reversing steam engine with pulley and flywheel, feed pump and feed water heater, with means for operating both throttle valve and reversing gear from the derrick, and ample spares.
1 72 by 20 feet wooden derrick and rig.
1 set rig irons, 4½-inch shaft.
150 feet wire telegraph cord.
2 grooved pulleys for same.
30 feet 16 inches wooden conductor.
1 derrick crane and hoist.

Drilling Tools.

All joints, 2¾ inches diameter by 3¾ inches long, 7 flat threads per inch, 4-inch squares for wrenches, except 5-inch tools with 2-inch by 3-inch joint, 8 sharp threads, and 3¼ inch squares for wrenches.
1 spudding shoe for 2¼-inch cable.

1 No. 2 Barrett oil-well jack.

1 $1\frac{3}{4}$-inch temper screw (5 feet 6 inches to let out).

2 New Era rope sockets, $2\frac{1}{4}$ inches cable. 2 do., 2-inch by 3-inch joint.

1 set jars, $5\frac{1}{4}$ inches diameter, $4\frac{1}{2}$-inch stroke.

1 ” $4\frac{3}{8}$ ” 2-inch by 3-inch joint.

1 stem, $3\frac{1}{2}$ inches by 30 feet, with 2-inch by 3-inch joint.

2 stems, $4\frac{1}{2}$ inches by 30 feet. 2 stems, $4\frac{1}{2}$ inches by 20 feet.

1 auger stem, 4 inches by 16 feet. 1 auger stem, $4\frac{1}{2}$ inches by 10 feet.

1 set boxes and pins, $2\frac{3}{4}$-inch by $3\frac{3}{4}$-inch joint. 1 do., 2-inch by 3-inch joint.

1 ” ” templates $2\frac{3}{4}$-inch by $3\frac{3}{4}$-inch joint.

1 ” ” ” 2-inch by 3-inch joint.

1 set tool wrenches for 4-inch squares. 1 do. for $3\frac{1}{4}$-inch squares.

1 set bit gauges.

1 200 lbs. spudding bit for 18-inch hole.

1 set of bits (200 lbs. steel), 14 inches.

1 ” ” ” for $12\frac{1}{2}$-inch hole.

1 ” ” ” ” 10 ”

1 ” ” ” ” $8\frac{1}{4}$ ”

1 ” 120 ” ” $6\frac{5}{8}$ ”

1 ” 100 ” ” $5\frac{3}{16}$ ” 2-inch by 3-inch joint.

1 casing head, 2 outlets, for 10 inch casing.

1 ” ” ” $8\frac{1}{4}$ ”

1 ” ” ” $6\frac{5}{8}$ ”

1 ” ” ” $5\frac{3}{16}$ ”

4 sand line caps to suit above.

1 each oil savers for $8\frac{1}{4}$, $6\frac{5}{8}$, and $5\frac{3}{16}$ inch casing heads.

BAILERS.

1 conductor bailer, $10\frac{5}{8}$ inches by 5 feet long.

1 wrought-iron bailer, $4\frac{1}{2}$ ” by 20 ”

1 ” ” 6 ” by 25 ”

1 ” ” 8 ” by 25 ”

1 sand pump, 8 inches diameter.

1 ” 6 ”

1 ” $4\frac{1}{2}$ ”

FISHING TOOLS.

1 set jars for 6-inch hole, 36-inch stroke.

1 ” ” 5-inch hole, 2-inch by 3-inch joint.

1 horn socket with bowls to suit casing.

1 slip socket, 8 inches, with bowls to suit 10-inch casing.

1 do., 5 inches, with bowls to suit $6\frac{5}{8}$-inch casing, 2-inch by 3-inch joint.

1 boot jack, to suit casing.

1 horse-shoe trip knife, $\frac{7}{8}$-inch pin.

1 sucker rod jar for rope knife, $\frac{7}{8}$-inch pin.

1 rope knife sinker, $\frac{7}{8}$-inch pin.

1 2-wing rope grab for $5\frac{3}{16}$-inch hole. 1 rope spear grab for $5\frac{3}{16}$-inch hole.

1 spud, 8 feet, for 8-inch hole. 1 spud, 10 feet, for 5-inch hole.

1 sand pump bailer grab.

Casing Elevators, &c.

1 pair casing elevators, for 12½-inch casing.
1 „ „ 10-inch „
1 „ „ 8¼ „ „
1 „ „ 6⅝ „ „
1 „ „ 5 3/16 „ „
1 wedge ring for 12½ and 10 inch casing.
1 „ „ 8¼, 6⅝, 5 3/16 inch „
2 60-ton hydraulic jacks, 12-inch lift.
1 26-inch iron single lower pulley block for wire rope with hook.
1 24 „ double upper „ „ „
1 driving clamp for each size of stem square.
1 steel shoe for each size of casing.
1 drive head for each size of casing.

Cables, Wire Ropes, and Belting.

1 1,500 feet by 2¼ inches manilla drilling cable.
1 2,000 feet by 2¼ inches „ „
2 2¼-inch bull ropes.
2 pairs 2¼-inch bull rope couplings.
1 2,000 feet by ½ inch diameter sand line.
1 1,500 feet by ½ inch „ „
1 450 feet by ¾ inch block rope, breaking strain, 17 tons.
1 24 feet by 1¼ inch loop dead line for supporting blocks.
2 90 feet by 10 inches hair belting with fasteners.

Steel Wire Cable Drilling.—The large size and expense of manilla cables has led to many endeavours to introduce with success a steel wire rope for drilling. When a drilled hole is reduced below 6 inches diameter, a 2 to 2½ inch manilla cable does not sink freely where there is liquid in the hole, and the number of strokes has to be decreased accordingly. The displacement of liquid is also excessive when the ratio of area of cable to diameter of well is so close. Steel ropes should also, under normal working, wear much longer than manilla, which suffers deterioration from alternate wettings and dryings as well as from abrasion.

Although steel cable drilling is performed to some extent with ordinary cable plants, slightly modified to suit the change, it has not yet met with general favour, and least of all in America where its employment would be most expected. The elasticity so characteristic of the manilla

cable is to a large extent absent in steel cables until a depth exceeding 1,000 feet is reached, and in West Virginia and some other States of America, where there is a certain employment of steel cables, it is customary only to replace the manilla cable after a depth of 1,000 feet has been reached.

The positive rotation of the drill has been one of the assumed difficulties in steel cable drilling, as a wire rope cannot be wound round the handle of the temper screw like a hempen rope. The rotation has in practice been accomplished either by using a short rope and unwinding it entirely from the drum each time the tools have been lowered and then coiling it round the temper screw, or attaching a special appliance above the tools which automatically rotates the tools a proportion of a revolution at each stroke. In the former case an additional length of cable has to be spliced on each time the maximum depth to which it will extend has been reached. The rotating devices generally derive their action from some ratchet arrangement which causes the twisting of the tools at each stroke.

Many drillers of experience maintain that no special rotation apparatus is necessary for wire-rope drilling, as the alternate removal and application of the weight of the tools on the wire rope causes it to spin considerably and, according to the law of chances, two successive blows on the same spot would be very improbable. Considerable use of steel cables has been made in the Canadian oil-fields, and no special rotating device has been found necessary in those fields.

Canadian Pole Tool System.—The Canadian Pole Tool system of boring is perhaps the most useful all-round prospecting rig which can be purchased, and it is especially suitable for those regions where excessive caving makes it necessary to have some positive method of rotating the bit. The Russian and Galician systems are only modified pole tool processes in which the original ash drilling poles have been replaced by iron rods.

Rig.—The Canadian rig is a simple woodwork framing in which one shaft and two "spools" running in bearings transmit the various motions desired. The drive is taken by a pulley attached to the main shaft on which are also keyed two "band" pulleys which communicate by belting with two "spools" running immediately overhead in the upper part of the framework. The main shaft is also provided with a disc crank on one of its extremities which, through the medium of a "pitman" or connecting rod, transmits an oscillating movement to an overhead pivoted walking beam when the engine is run. The band and spool pulleys are flanged to prevent the driving belts which surround them from slipping off, as the belts are always left loosely in position, and the spools are put into action by jockey pulleys which are drawn firmly inwards by levers against the belts. One spool wheel operates the sand line when cleaning out the well, the other is used for raising and lowering the rods and tools as they are inserted or withdrawn from the well. To the walking beam is attached at the centre of oscillation a "slipper out" which is used for giving the feed during drilling, and is merely a clutch gear attached to a spindle upon which is coiled a chain leading to the "spring pole" overhanging the well. At the end of the beam the chain several times encircles a fitting so that when the tools are released by the clutch gearing, the greater part of the weight is taken by the beam and not by the clutch.

Fig. 51 shows the general arrangement of a Canadian standard rig.

Drilling Tools.—The tools consist of chisels or "bits," sinker bar or stem, jars, substitute and wooden ash drill poles to the surface. Sometimes wing guides are coupled to the stem to keep the tools straight in inclined strata, and an under-reamer is occasionally connected also. The tools are very similar to those used for the cable rig, the only important difference being the ash drill poles which are used instead of a rope. The bits are sometimes fluted and sometimes flat,

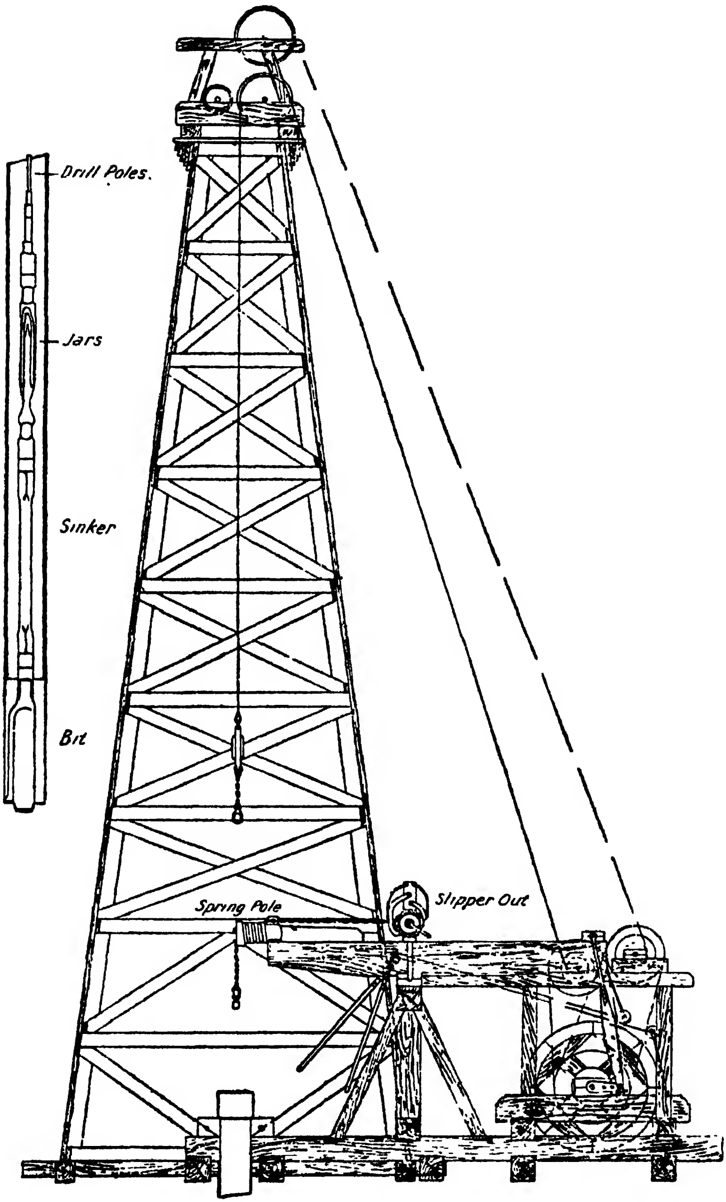

FIG. 51.—CANADIAN RIG.

Showing string of tools on left.

with or without side wings, and not infrequently eccentric bits are employed to enlarge the hole sufficiently to allow the casing to follow. The pole tool system permits under-reaming much better than cable systems, as the action is positive and definite, the rotation of the rods at the surface assuring the twisting of the bit in the hole. The sinkers have diameters between 2½ and 4 inches, and lengths from 10 to 30 feet, and the jars are similar to those already described under cable tools.

The poles are of 2 to 2½ inches hexagonal or round trimmed ash, in lengths of about 18 feet, to the extremities of which are riveted iron straps which partially encircle the rod and have a screwed pin or a box joint. Sometimes two such rods are coupled together by means of two iron straps encircling the pole, making 36-feet lengths. The joints are always screwed taper to take up wear, and there are six to eight threads to the inch. The figures below give the Canadian standard sized joints for poles and other attachments :—

No.	Diam. at Point.	Diam. at Shoulder.	Length.	Threads per Inch.	Size of Wrenches.	Diam of Collar.
	Inches.	Inches.	Inches.		Inches.	Inches.
1	1½	2¼	3	8	2¼	3¼
2	1¾	2¾	4	8	3	4⅛
3	2	3	4	8	3	4⅜
4	2½	3½	4	8	3½	4⅞

The rods are raised and lowered by a pole box, and swivel on a ⅞-inch steel wire rope worked by one of the spools, a suitable fork being pushed beneath the collar of each joint as it reaches the mouth of the well. The descent of the rope after a rod has been raised and placed aside in the derrick is brought about by a heavy rope weight coupled to the rope above the swivel-screwed joint by which they are lifted. When the tools and rods have been lowered to the bottom of the well, suitable short lengths of rods are attached to give the desired distance to couple up the feed chain on the

walking beam by a drill swivel, the feed being adjusted by the slipper out clutch during work.

In addition to the ordinary sand pumps and bailers which can be operated by a steel wire line, augers can be lowered and rotated by the rods. The common fishing tools consist of horn sockets and slip sockets which can be guided over lost and broken rods by "bonnets," which are simply bell-mouthed guide pieces which can be attached to the tools.

SPECIFICATION OF CANADIAN RIG AND TOOLS FOR DRILLING 2,000 FEET WELL.

1 steam boiler capable of evaporating 1,000 lbs. of steam per hour at 100 lbs. pressure, with Colonial type fire-box, fusible plugs, feed pump, injector, and spares.

1 horizontal 12 by 14 inches single cylinder reversing steam engine, with pulley and flywheel, feed pump and feed-water heater, with means of operating steam admission and reversing gear from a distance.

1 derrick, 56 by 18 feet, square at base, $4\frac{1}{2}$ feet at top.

1 heavy drilling rig for 2,000 feet, including bolts, beams, husk-blocks, snatch post, spring pole, &c.

SAND PUMPS AND BAILERS.

1 mud pump,	12	inches by	6	feet long,	with hinged bail and	drill pin.
1 sand pump,	$10\frac{3}{4}$	„	18	„	„	„
1 „	$7\frac{1}{4}$	„	36	„	„	„
1 „	$5\frac{1}{4}$	„	36	„	„	pole pin.
1 „	$4\frac{1}{4}$	„	36	„	„	„

FISHING TOOLS.

1 fishing jar, $1\frac{3}{4}$ by $2\frac{3}{4}$ inch box and pin.
1 pole hook for 10-inch hole.
1 9-inch horn socket, with 3 dogs.
1 $6\frac{3}{4}$-inch two-legged socket, with two dogs and springs.
1 $5\frac{3}{4}$ „ „ „ „
1 $4\frac{1}{4}$ „ „ „ „
6 bonnets for sockets for 5-inch, 6-inch, 7-inch, $8\frac{1}{2}$-inch, 10-inch, and 12-inch casing.
1 wire rope knife.
1 „ spear.

CASING, ELEVATORS, &C.

2 casing swivels for 12-inch casing.
2 ” 10 ”
2 ” 8½ ”
2 ” 7 ”
2 ” 6 ”
2 ” 5 ”
6 sets wooden clamps for above casing.
4 2-inch casing clamp bolts, with heavy nuts.
2 casing chains, ½ and ⅝ inch ring and hook.
3 clevices and pins for casing swivels.
1 extra heavy quadruple block, with 15-inch sheaves and swivel head.
1 ” treble ” ” ” shackle.
1 steel shoe for each size of casing.

CABLES, WIRE ROPES, AND BELTS.

200 feet 1¼-inch manilla rope.
200 feet ¾-inch ”
200 feet ⅜-inch ”
1 ⅞-inch by 120 feet draw line, with 2 eyes.
1 ⅝-inch by 650 feet block line, with 2 eyes.
1 ⅝-inch by 2,500 feet sand line, with 2 eyes.
2 12-inch by 65 feet double leather draw belts.
½ gross belt laces.
1 12-inch by 42 feet drive belt.
1 pair belt clamps.

DRILLING TOOLS.

2 13¼-inch bits, 250 lbs. steel, 3 by 4 inch pin-joint.
2 11¼ ” 180 ” ” ”
2 9½ ” 150 ” ” ”
2 8 ” 110 ” 2½ by 3½ inch ”
2 6½ ” 90 ” ” ”
2 5½ ” 75 ” 1¾ by 2¾ inch ”
2 4½ ” 60 ” ” ”
2 11¼-inch undercutting bits, 3 by 4 inch ”
2 9½ ” ” ” ”
2 8 ” ” 2½ by 3½ inch ”
2 6½ ” ” ” ”
2 5½ ” ” 1¾ by 2¾ inch ”
2 4½ ” ” ” ”
1 7-inch by 10 feet long sinker, 3 by 4 inch joint.
2 5 ” 15 ” ” 2½ by 3½ inch joint.
2 3½ ” 15 ” ” 1¾ by 2¾ ”
2 3 ” 15 ” ” ” ”
1 6¼-inch jar, 3 by 4 inch box, 2½ by 3½ inch pin.
1 5⅛ ” 2½ by 3½ ” 2½ by 3½ ”

1 $4\frac{1}{8}$-inch jar, $1\frac{3}{4}$ by $2\frac{3}{4}$ inch box, $1\frac{3}{4}$ by $2\frac{3}{4}$ inch pin.
1 substitute, 3 by 4 inch box, $2\frac{1}{2}$ by $3\frac{1}{2}$ inch pin.
1 " 3 by 4 inch pin, $2\frac{1}{2}$ by $3\frac{1}{2}$ inch box.
1 " $2\frac{1}{2}$ by $3\frac{1}{2}$ inch box, $1\frac{3}{4}$ by $2\frac{3}{4}$ inch pin.
1 " $2\frac{1}{2}$ by $3\frac{1}{2}$ inch pin, $1\frac{3}{4}$ by $2\frac{3}{4}$ inch box.
1 " $2\frac{1}{2}$ by $3\frac{1}{2}$ inch box, pole pin.
1 " $1\frac{3}{4}$ by $2\frac{3}{4}$ " "
1 " $2\frac{1}{2}$ by $3\frac{1}{2}$ inch pin, pole box.
1 " $1\frac{3}{4}$ by $2\frac{3}{4}$ " "
2 heavy tool wrenches for $4\frac{1}{2}$ inch square.
2 " " 4 "
2 " " 3 "
2 knock wrenches.
1 catch wrench.
1 key wrench for iron poles.
1 chain lever, heavy.
56 drill poles, 36 feet long.
4 tubular hand poles.
1 pole swivel, with chain.
1 drill swivel.
1 sand pump swivel.
1 sand pump hanger and chain.
1 pole hook.
1 3-inch clevice and pin for top of derrick.

Galician System.—The Galician system is practically a normal Canadian rig in which light iron rods are used instead of ash poles.

Russian Freefall System.—The large diameter of wells in the Baku oil-fields and the specially caving nature of the strata met with have led to the adoption of a modified pole tool system which well suits the local conditions. The tools consist of a chisel or bit, under-reamer, sinker bar, and freefall, connected by $1\frac{1}{2}$-inch square iron rods which extend to the surface. The tools are operated by a geared frame of heavy design driven by belting from an engine or motor in the derrick. The geared frames vary somewhat in design, but they are all provided with means of operating four distinct shafts or combinations which drive by gearing or otherwise three drums and a crank-shaft. One slow geared shaft in the front of the frame

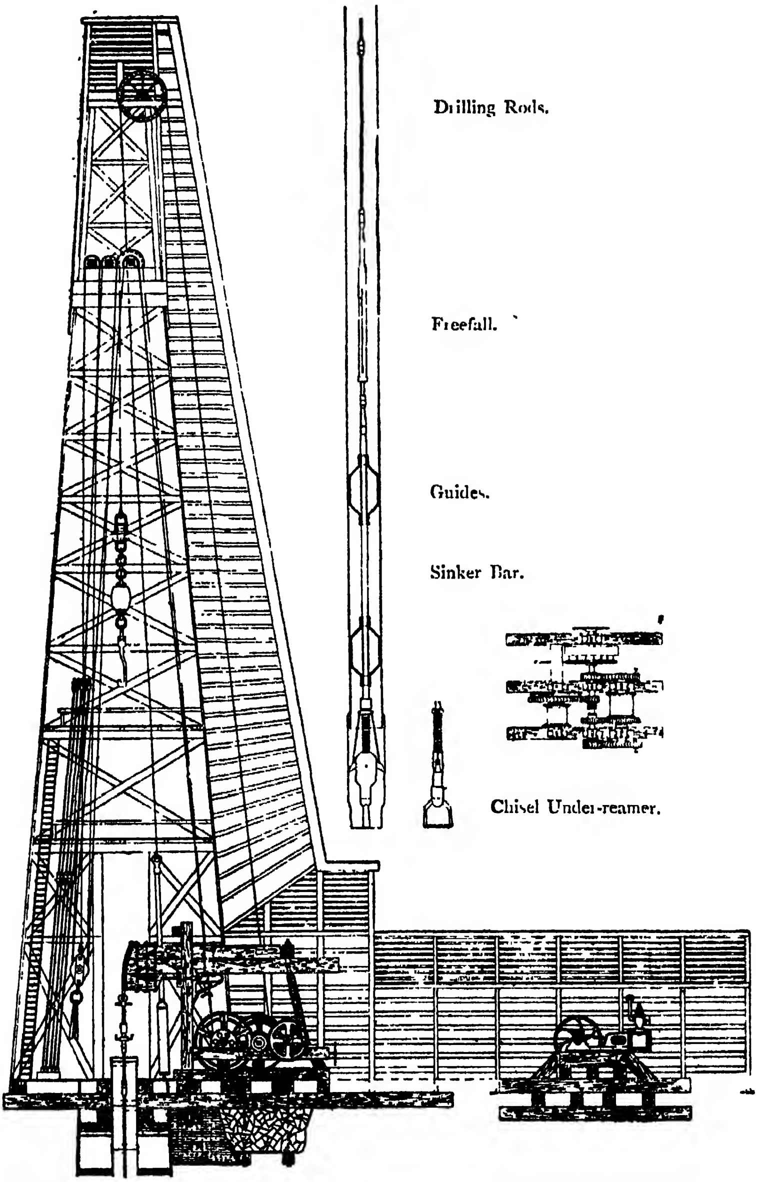

FIG. 52.—RUSSIAN DRILLING RIG.
Showing string of tools on right.

is fitted with a drum and powerful side brake for raising and lowering the tools through a distance of about 50 to 60 feet as the rods or tools are being connected or disjointed. Another larger drum geared for high speed is used for raising and lowering the bailer and sand pump, and a third drum shaft, also in combination with a brake, operates the heavy pulley blocks which are used for manipulating the casing. One of the above shafts which can be disconnected from the drum or a fourth shaft is fitted with crank discs, which by connecting rods impart an oscillating motion to a walking beam pivoted on the upper part of the frame. The cranks are provided with holes at different radii to enable a varied stroke to be given to the beam by altering the position of the crankpins, and means are arranged for putting in and slipping out of gear the various drums as occasion demands.

The tools are screwed together singly and lowered into the mouth of the well by means of either a 1¼-inch English welded chain, or a 1½ to 2½ inch steel wire cable attached to the front drum, a very heavy swivel hook with safety catch being attached to the chain or rope for the purpose. The 1¼-inch square rods are generally 21 feet long, screwed with taper threads, and are left coupled up in pairs to make 42-feet lengths after the depth of the well exceeds about 70 feet. A sheet-iron cap with a hole sufficiently large to pass the collars of the rods is placed over the casing mouth when the tools have been lowered, and this is retained in position until the tools are again withdrawn to the surface, thus preventing any object from falling down the well.

When the tools have been lowered to the bottom of the well the correct distance is made up with short rods to connect a temper screw suspended from the arm of the walking beam which overhangs the well. The weight of the tools suspended from the walking beam is generally counterbalanced by the attachment of weights to the opposite end of the beam, thus causing the machine to run evenly and lessen the power required. When everything is ready for actual drilling the

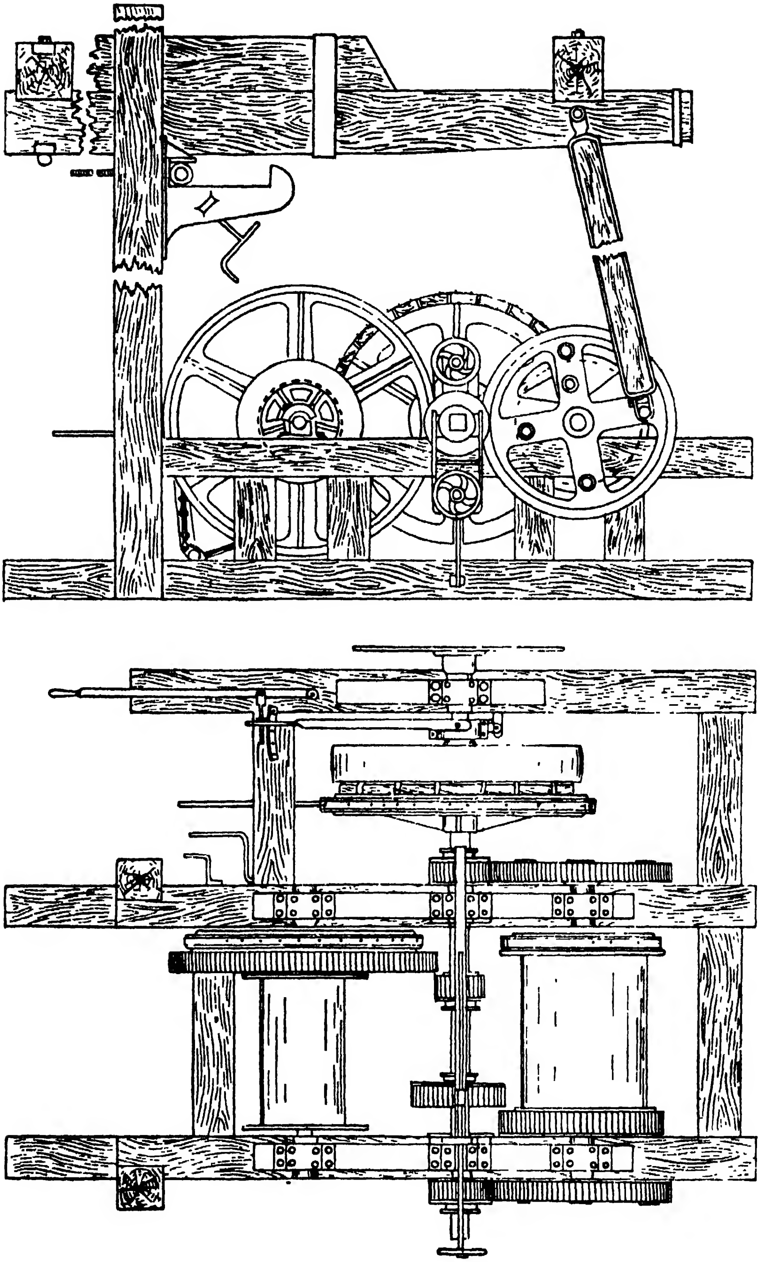

Fig. 53.—A Common Type of Russian Boring Frame

gearing is arranged for driving the walking beam and the belting slipped from the loose to the fast pulley. Whilst running slowly the temper screw is so adjusted that the freefall comes into play, each extreme downward movement causing the internal spindle of the freefall, to which the chisel, under-reamer, and sinker are connected, to attach itself to a projection on the body of the instrument on which it rests during the upward stroke, until a sharp movement transmitted to the rods by an operator at the surface causes dislodgment, and the bit, &c., to fall freely. The speed is then accelerated to between twenty and thirty strokes a minute, the temper screw being fed out as demanded, and the rods slightly rotated at each stroke to cause the bit to strike evenly over the whole surface of the hole. As quite a considerable amount of power is required to twist and release the freefall when heavy tools are employed, the "handle bars" are generally provided with two pairs of handles, and they are clamped to the rods in any position by a pair of bolts.

When a certain distance has been drilled, varying from 2 to 7 feet according to the character of the ground, the pulverised material impedes the action of the freefall, and prevents the striking of a direct blow, and the tools are raised for cleaning out the well. The walking beam, which is so mounted that it can be pushed about a foot back from the centre of the well, is so adjusted, and the rods and tools are left standing vertically in the derrick as raised, their displacement being prevented by iron straps in the upper part of the derrick, where an assistant is stationed to attach and release the swivel hook as each pair of rods is lifted.

The cleaning drum is provided with a brake, and is generally allowed to run loose as the sand pump or other cleaning tool is lowered into the well on a $\frac{5}{8}$ or $\frac{3}{4}$ inch wire rope. The bailers, sand pumps, &c., used for cleaning the debris are of the ordinary description, except that they are much larger. A very common form of Russian pump consists of a lower enlarged portion, at the base of which is fixed an

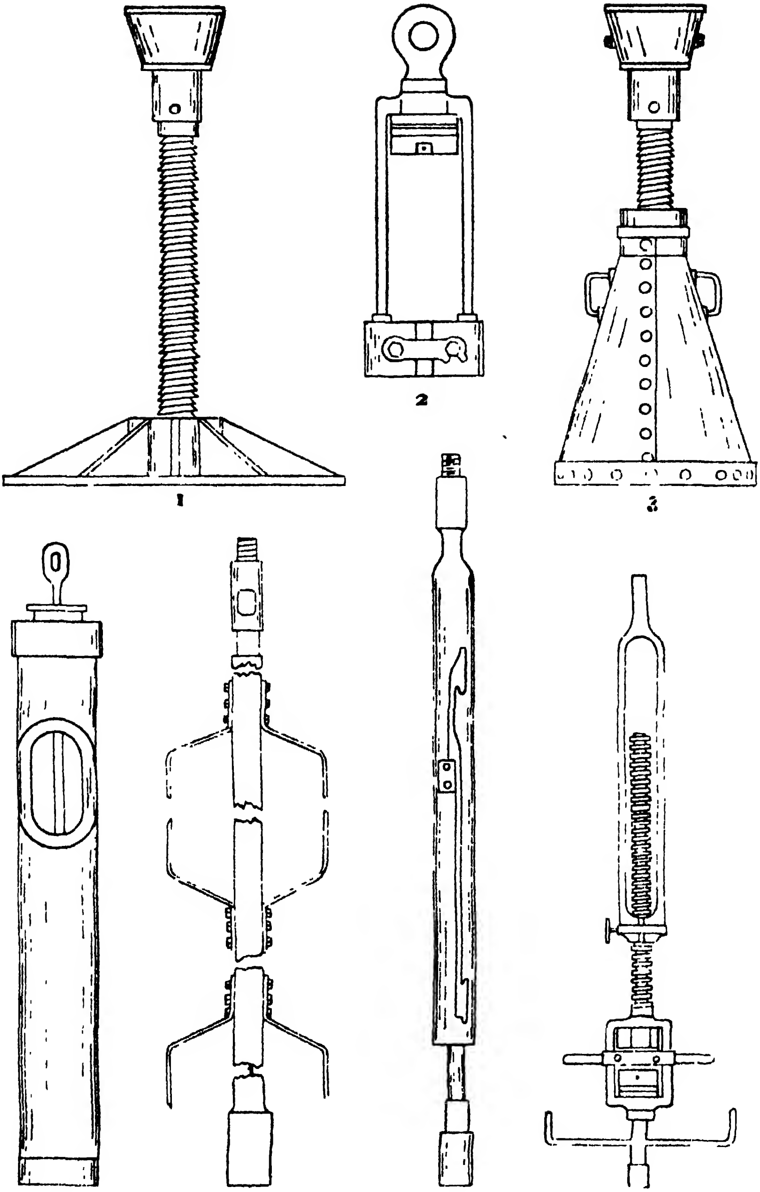

FIG. 54.—BORING REQUISITES AS USED IN RUSSIAN OIL-FIELDS.

1. Screw Jack for Pressing Casing.
2. Safety Hook for Raising Rods.
3. Jack for Raising Casing.
4. Sand Pump.
5. Sinker Bar with Guides.
6. Freefall.
7. Temper Screw.

ordinary flap valve, and a long upper part about 6 inches in diameter, inside which works a plunger attached to a long steel rod. If the plunger be raised and allowed to sink a few times after the pump has been lowered to the base of the well, the mud and slush are drawn in and fill the vessel.

The chisels or bits are heavy forged steel, often with side wings, and the Russian form of under-reamer (see Fig. 52) is screwed to the chisel, and consists of a solid rectangular body machined to take two cutters pivoted at a central position by a strong pin. The two cutters are kept extended by a steel spring encircling the body externally, which forces upwards a cross-bar connected to the cutters by two links. The cutters are so designed that they only expose the cutting edges when fully extended to a diameter about 2 inches larger than the casing through which the work is proceeding. When forced downwards against the spring the cutters pass tightly through the casing, the flat part only coming into contact with the sides of the casing, expanding out to their full width on emerging from the casing shoe. Fig. 55 shows a form of combined chisel and under-reamer patented by a Mr Beiring, of Baku, and this has been proved capable of performing good work in practice. The sinker bar is nothing more than a 4 to 6 inch square bar from 10 to 20 feet long, screwed for attachment to the other tools, and generally provided with two sets of guides that can be changed for different sizes of casing to keep the chisel central.

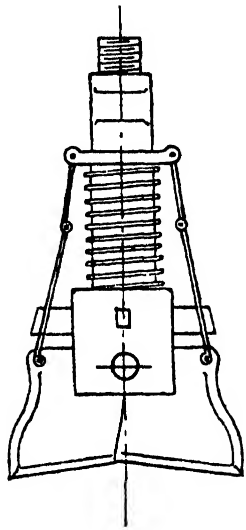
FIG. 55.—BEIRING'S COMBINED CHISEL AND UNDER-REAMER.

In the Russian oil-fields the caving nature of the strata makes it necessary to keep the casing near the tools, con-

sequently it is customary after each 5 or 6 feet of drilling to rivet on a 4 feet 8 inches length of casing, and lower it into position, never omitting at the same time to move the column up and down several times to keep it liberated. Heavy three and four fold pulley blocks suspended from timbers at the top of the derrick are used for this work of freeing the casing, and the pulley rope is operated by one of the drums on the geared frame. If the tubes become too tight to be moved by the pulley blocks before they have been sunk 300 to 400 feet below the preceding column, it is usual to make attempts to liberate them by using hydraulic jacks as well as the pulley blocks, a new column only being lowered when all reasonable measures have failed to free the preceding one.

Fig. 53 illustrates a good type of boring machine used in the Baku oil-fields for drilling to depths of 2,500 feet. There are numerous modifications of geared frames in general use, but the actual speed of drilling does not vary much from an average of 5 to 6 feet daily in wells of 2,000 feet depth.

Rotary and Flush Drills.—In certain oil-fields where thick beds of "running" or "quick" sands have to be passed before the oil strata are reached, as in parts of Texas and Louisiana, it is usual to use a flushing system; indeed, many loose sandy formations can only be passed in this way. There are numerous rotary flushing systems in the market, but they closely resemble each other in the main features, the claims of different makers lying chiefly in details of construction. Some rotary systems aim at the extraction of a core, whilst others make no pretence at the formation of a core, and permit all the disintegrated material to be washed away.

Rotary drills are furnished with a "rotary" or geared table which is usually designed in such a way as not only to rotate the flushing rods but the casing also, if so desired. A rotary gear sold by the Southern Well Works, Beaumont, Texas, and largely used in the Texas oil-fields, is shown in

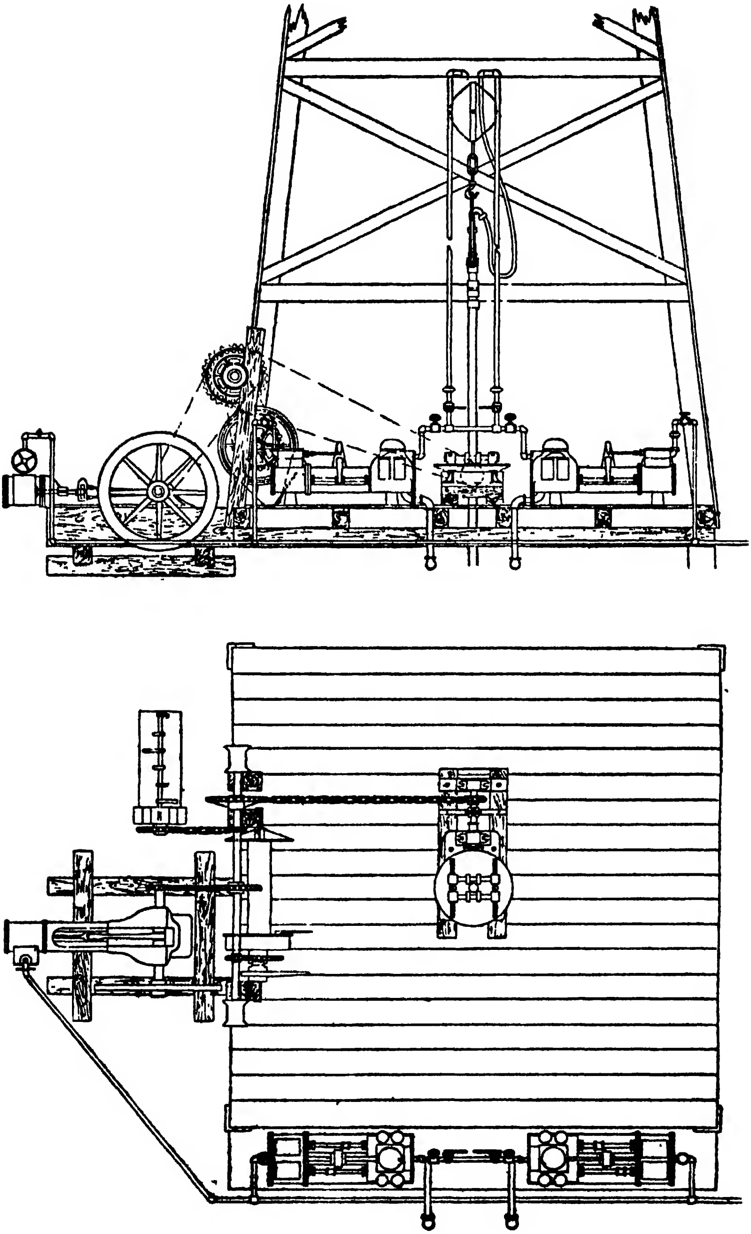

FIG. 56.—ROTARY FLUSH TYPE OF DRILLING RIG.

Fig. 56, capable of rotating casing up to 12-inch. A hollow cast-iron table, with bevel gearing on its lower outer edge, works freely on a base plate to which is led a shaft with a mitre pinion engaging with the bevel gearing of the table. On the upper face of the table is fitted a device by which casing or rods of any size between 2½ and 14 inches can be firmly held by grip rings, which, whilst holding the casing or rods, enables them to move readily in a vertical direction. The driving shaft is provided with a clutch for throwing the "rotary" table in and out of gear, and motion is transmitted by a driving chain engaging in sprocket wheels. To one side of the derrick is fitted a wooden framework on which are two shafts connected by a transmission chain working on sprocket wheels. The driving shaft receives the drive by chain from the engine, and on the second shaft is fitted a hoisting drum with brake pulley for manipulating the pulley rope that operates the casing or rods. Sometimes a bailing drum is also attached to the shaft with an independent clutch and brake.

When the strata are very soft the casing is furnished with a steel cutting shoe and rotated whilst water is forced down internally by a force pump at the surface. To allow for the rotation and descent of the casing a specially constructed hydraulic swivel is attached to a cap which screws into the top of the casing, and a flexible, armoured, rubber hose extends from the swivel to the pump. The casing and swivel attachments are suspended by a hook from pulley blocks manipulated by the before-mentioned hoisting drum so that the casing can be lowered as required. When flushing bits are used they are lowered on specially strong 2 to 3¼ inch internal diameter tubing ⅜ to ½ inch thick, often fitted with square-threaded joints and strong sockets. The drilling tubes are made in 18 to 20 feet lengths, and screw to butt to make a tight connection.

Duplex, direct-driven steam pumps are employed, specially manufactured to take muddy water, with capa-

cities of 150 to 200 gallons a minute at 170 lbs. pressure. It is customary to have two pumps coupled up to the tubing connected with the swivel, so that in the event of one failing the second can be started in a few minutes, and the danger of a lost tool or rising plug avoided, such as can easily follow the suspension of the flow of water and consequent loss of pressure at a critical juncture.

The flushing bits used by a rotary drill consist of short steel chisels threaded to suit the drill tubing and perforated to eject a fine powerful stream of water towards the drill edge. The common drill, which can be used for percussion as well as rotation, has a flat edge, but for rotation only in soft ground the fish tail bit is often used. In hard ground and rock it is necessary to employ a rotary steel cutter attached to a core-barrel 10 to 20 feet long and of a diameter equal to that of the cutter. An annular space is thus cut by the rotary cutter, and the core stands vertically in the core-barrel, its extraction being accomplished by pumping down fragments of rock which will plug the space between the cutter and core, and so cause its seizure and removal with the tools.

The water is pumped down the casing or well tubes at a pressure which ensures sufficient velocity in the annular space behind the casing or around the flushing tubes to raise the particles of sand and detached debris to the surface. The quantity of water needed varies immensely with the absorptive capacity of the strata penetrated and the character of the beds. An extremely slow vertical movement of water will carry upwards fine sands and such minute particles as those composing clay, but a high velocity is needed to raise to the surface particles of coarser sands and fragments of detached rock. A definite sized grain of sand will take a definite time to travel a certain distance in a vertical stream of water with a fixed velocity, the speed varying directly with the rate of flow of the flushing water, and inversely with the size or weight of the particles of sand, &c., to be raised.

When some highly porous sands are penetrated, the whole

of the water pumped down a well will often be absorbed, and no liquid will reach the surface. In such cases it is only possible to make progress by mixing clay with the water and pumping down the well a thick puddle which enters the pores of the sands and renders them partly, if not entirely, impermeable. In the Texas oil-fields special puddling machines are built to mix clay with the water prior to its delivery by the pump to the well, and porous seams and fissures which would otherwise prevent further progress are filled or sufficiently plugged to allow the water to reach the surface with the detached debris in suspension. By the liberal employment of thick clay puddle, highly porous gravels and even badly caving ground can be passed and cased off.

When very hard ground is struck upon which no headway can be made by steel rotary cutters, it is usual to attach a plain core-barrel and feed in with the water at regular intervals a small quantity of chilled steel shot or adamantine. The shot or particles of adamantine find their way beneath the core-barrel in which slots are cut to facilitate their progress to the cutting edge, and allow the water to pass where they are rotated and wear away the rock. So effective is chilled shot drilling in hard material that by its aid lost steel bits which have defied all efforts at recovery can be cut out (see Fishing, p. 218).

When drilling by rotating the casing in conjunction with a water flush, it is advisable to raise the casing and replace the cutter for a plain steel shoe before setting to exclude upper water sources, as the serrated edges might leave spaces for the admission of water past the cutting shoe.

When using a flushing bit or rotary core cutter it is advisable to keep the casing as near the tools as possible, but when hard ground or rapidly alternating hard and soft strata are being passed, the casing can only be kept near the bits by under-reaming. There are many rotary under-reamers made, but they are not very satisfactory and are only used in enforced circumstances. In hard ground the

wear on the under-reaming cutters is very great and they need constant dressing to be kept up to size.

If a fall or "caving" of strata covers the tools, they can often be freed by maintaining the water pressure and carefully drilling upwards, and giving the tools a reciprocating motion whilst they are being rotated.

Rotary flushing systems are not generally favoured for petroleum drilling, as the water sometimes conceals the identity of the beds passed and occasionally prevents the admission of oil into the well. An oil sand when washed with water presents no appearance of being oil-bearing and is usually a brilliant white or light grey sand, so that unless there is a heavy gas pressure which more than counterbalances the water pressure a productive stratum may be passed unnoticed. In districts where flushing systems are largely used, the approximate depths of oil-bearing strata are known, and the occurrence of sand at about the estimated depth is usually sufficient justification for testing the well.

The following example illustrative of the subject under consideration, taken from a paper by Mr I. N. Knappe,* will explain the danger of flush drilling:—"One of the several visits I have made to the Texas oil-fields was in October 1901, and on that occasion I saw a well on the Hogg-Swayne tract of Spindle Top that had been drilled into the known oil horizon by the hydraulic rotary method, but made no showing of oil, notwithstanding that within a radius of 250 feet around it, were a number of gushers, and the original pressure of Spindle Top wells had been reduced but little. After this well had been agitated and bailed for six days, it finally gushed and flowed a solid 6-inch stream of oil until shut in. If this had been a prospect well in a new district where the oil horizon had not been definitely located, there evidently would have been a strong possibility of passing the oil stratum without revealing its productive capacity."

* "'Mud Scow and Stove Pipe' System for Sinking Wells through Soft Formations." I. N. Knappe, *Steven's Institute Indicator.*

When flushing and rotating the casing, or even drilling and flushing with bits, great difficulty would be found in excluding overhead water after the oil stratum had once been penetrated by the drill, consequently in unknown regions it is advisable to proceed some distance ahead of the casing or the full-size hole by drilling with a diminished size of bit. In the event, therefore, of an oil stratum being reached the casing can be driven into an upper bed of clay or impervious material and "set" to exclude all surface water before proceeding deeper with the full diameter.

In some oil-fields, such as those of Baku, where enormous quantities of sand are raised with the petroleum, the use of a flushing system is entirely excluded when the oil series has once been reached, as immediately an exhausted or partially exhausted oil sand is reached the water disappears and no amount of mud pumping will render the stratum impervious. If, as is frequently the case, neighbouring wells are drawing supplies of oil from these upper sands, the admitted flushing water quickly finds its way to these and causes their temporary if not permanent loss as productive units. Some attempted flush drilling in the Bibi-Eibat oil-field of Russia actually had the above effect, and any efforts to introduce the flushing system into the Baku fields, had it proved a success, would certainly have been frustrated by legislation.

In Roumania the use of flushing drills has been the object of much hostile criticism from a large part of the producers who stoutly affirm that the oil sources become flooded and productive wells injured in the neighbourhood of flush drilling. The advocates of flushing systems just as emphatically deny the possibility of injury, asserting in support of their contention that the system will only work satisfactorily when the greater part of the water pumped down is recovered, its return in porous strata being brought about by keeping the casing close to the bits and using clay.

In new oil ground no water enters the oil beds as they are already fully charged with petroleum, and can admit no more

fluid, but water will rapidly enter partially depleted oil sands and either expel the oil from the vicinity or cause it to collect above the water and so possibly render neighbouring wells non-productive of oil. A fissure may lead to the admission of great quantities of water to local oil strata before it is passed or plugged with impervious material.

Calyx Drill.—This is a rotary core-extracting plant which has been introduced from Australia where excellent results have been obtained by its adoption. The cutter is made from a collar of high quality steel, fluted and cut into a number of long specially shaped teeth, which produce a chipping action when rotated by hollow flushing rods in the presence of a constant flow of water. The core is preserved in a core-barrel immediately above the cutter, and is broken off as before explained, and raised from the well, but the particular claim of the patentees lies in the "calyx," a long cylindrical vessel above the core-barrel which assists in guiding the tool as well as collecting the heavier particles of debris. Water forced down the flushing tubes emerges from the mouth of the cutters at a high speed which is maintained through the confined space surrounding the core-barrel and calyx, but when the large area above the calyx is reached the velocity of the water diminishes and the heavier particles drop back into the calyx in which they are subsequently raised with the tools.

The calyx drill works satisfactorily in soft rock and hard shales, but hard sandstones so quickly wear away the cutters that they are generally replaced by a "shot tube." The method of drilling is very similar to that before described, but the pressure of flushing water does not usually exceed about 60 to 70 lbs. In boring through clays the speed of drilling is greatly increased by frequently lifting the tools a few inches off the bottom and again lowering them. By this means the core is prevented from jamming and the cutter kept clean.

The Fauck "Rapid" System.—The "Rapid" system

can be arranged for ordinary "dry" drilling as well as by flushing, and it has been used with some success for drilling in the Carpathian oil-fields. The drilling is actually performed by percussion although rotary cutters are provided and excellent cores can be extracted, the desired end being achieved by the delivery of a rapid succession of blows transmitted by a short throw crank to the chain from which the rods or tubes are suspended. On the frame are fitted two drums actuated by belting from the driving shaft, one of which is used for operating the draw-rope for raising and lowering the rods and tools, the other for working the pulley blocks, or when not flushing for running the sand line.

The chief and somewhat special features of the "Rapid" system are the short and rapid strokes of the bit and the reversal of the flushing water. When core drilling, the water is pumped down the well between the casing and the boring tubes, in which latter it rises to the surface carrying with it debris and dislocated particles. The high velocity of the water in such a small area causes the liberation of the strata in layers, so that small cores in varying lengths rise to the surface in the boring tubes and are ejected with the flushing water. When ordinary Canadian percussion tools are used with the "Rapid," it is usual to give a stroke of about 20 inches, but for core drilling the strike does not exceed 3¼ inches.

Fishing for Lost Tools.—The recovery of a lost tool under normal conditions where there are no complications is not a difficult matter, but often its loss is accompanied by circumstances which render its extraction a long and tedious operation needing much judgment and skill.

The extraction of lost tools is often rendered more difficult by the damage their upper ends sustain as a result of continued blows by the released portions before the drill can be stopped or before their disconnection is realised by the drillers in charge. Such damaged ends have often to be filed or rasped by serrated steel blades lowered on rods or ropes

and worked from the walking beam before fishing can be undertaken with reasonable chances of success, whilst in certain cases the ends have to be milled by a milling cutter rotated by rods or tubes extending to the surface. Occasionally strings of heavy tools are dropped a thousand or more feet from the surface as the result of carelessness or accident, or fall back into the well as the consequence of a fractured rod or cable, in which case the casing is sometimes torn to shreds for hundreds of feet, and in the case of rods they form a twisted mass coiled up in indescribable confusion above the tools. When the casing is much damaged and the tools become wedged in the tubes, both may have to be withdrawn together, or as many of the rods must be disconnected as possible by lowering suitable hooks on heavy rods and unscrewing before the abstraction of the tools is entertained.

One common difficulty is the loss of part of the tools below the casing shoe, where they lie to one side and become during the subsequent fishing operations driven firmly into the side stratum, if of a soft nature, before their position is realised.

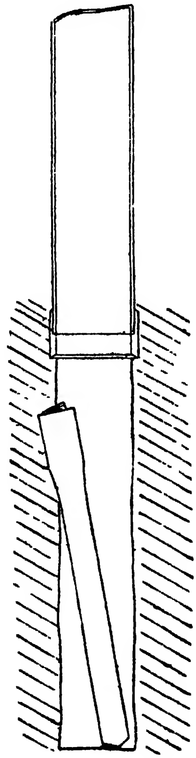

FIG. 57.—LOST BIT.

Showing how recovery is complicated when the bit is driven to one side beneath the casing.

The actual situation can be ascertained by lowering a "seal" or impression block upon which an impression is obtained of any object with which it comes in contact. An impression block consists of a sheet iron, bell-shaped disc attached to a screwed spindle for insertion on rods. A mixture of resin and soap or some viscous substance is prepared and spread over the lower

surface which has been previously prepared by inserting many nails which hold the material together. If the instrument is known to lie to one side where no clear impression could be obtained on a flat disc form of tool a conical-shaped impression block similarly prepared is lowered. Should the lost tool lie in such a position as indicated in Fig. 57, it cannot obviously be grasped by any ordinary tool, and it is necessary to force it into a more vertical position before some usual fishing tool is lowered. This can be accomplished by lowering on rods some class of hook which, when rotated, will push the tool into a central position, where it can easily be seized by any simple instrument. In the event of its return to the old position when released by the hook a few balls of clay may be dropped down the well to act as a support to the bit until it is gripped by the fishing tool. Sometimes cavings or sediment from the puddled liquid prevent the lost tools being reached, in which case the material must be cleaned out with small bailers and sand pumps, or, in certain cases when the drill is held by surrounding tough material, cautious drilling with a long spud is necessary to loosen the tool.

The loss of tools is often occasioned by a great inrush of sand which rises sometimes hundreds of feet in the well and completely covers the drilling tools, especially when prolific oil strata are struck in loose flowing sands. Whole strings of tools weighing several tons, with 1,000 feet of 1¼-inch drilling rods, have been violently ejected with a column of sand from some of the Baku wells when powerful new oil sources have been struck, and frequently hundreds of feet of oil sand rush up the casing and entomb the string of tools. The tools can sometimes be raised intact under such circumstances by patiently waiting until the plug is loosened by gas which often periodically breaks through, but more often their recovery can only be effected by lowering flushing tubes and washing the sand free with a powerful water flush; or, in special cases, where the well may be endangered by water, a crude oil flush.

In the Russian oil-fields where such occurrences are frequent, and where a large proportion of the fishing jobs are complicated by cavings, inrushes of sand, and rising plugs, all boring contractors and most private firms are provided with special flushing tubes and high-pressure pumps. The tubes in most popular favour are 2 to 2½ inches in diameter provided with special heavy coarsely screwed ends for rapid insertion and withdrawal. Under a pressure of 60 to 100 lbs. the sand is washed away by water or oil, additional lengths of tubing being added as the column descends.

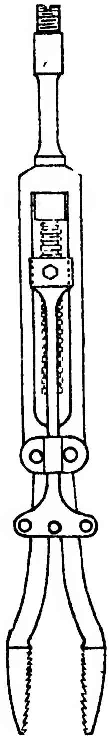

FIG. 58.—FISHING TONGS FOR RAISING SMALL LOST OBJECTS.

A somewhat delicate operation is to recover the broken end of a steel bit which usually falls to one side and contains no projections upon which a grip could be secured. Electro-magnets have been used for such purposes, but are not usually available, and some type of tongs which admit of movement of the limbs must be used. Fig. 58 shows a form which can be operated by rods from the surface, but specially designed limbs can be attached for seizing particular shaped objects.

If repeated attempts to recover an object lost in a well fail through constantly accumulating cavings or inaccessible position, two courses are open if no oil has so far been encountered, viz., either to abandon the well, or to cut up and drill through the lost object. Where the object is small and not composed of steel its demolition is usually a short operation, as it is partly cut up and partly driven aside by pulverising with a blunt steel bit weighted with the heaviest sinker bars available. When the formation

in the immediate vicinity is soft, large masses of iron may be driven aside in a few days by working with heavy tools, but when the formation is sufficiently hard to resist the entrance of any extraneous object its demolition is slow, as the whole mass has to be pulverised and raised in fragments. The destruction of a heavy irregular mass is assisted by adding hard flints as the work proceeds, thus forming a flat surface upon which the bits can work evenly.

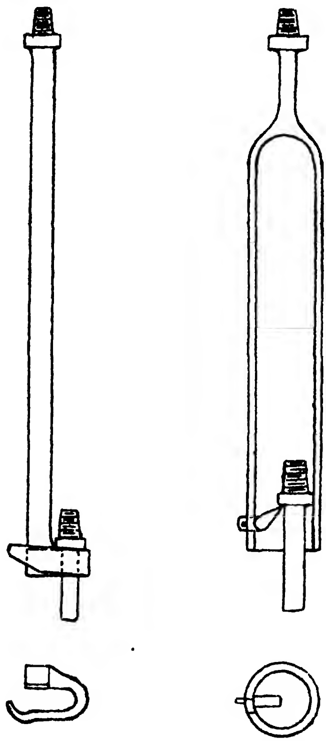

FIG. 59.—FISHING HOOK AND GRAB.

The only other method by which a well can be cleared of a hard steel object, where the formation resists its entrance laterally, is by enclosing the object in cement, after cleaning the well by washing, and then cutting through the solid mass with either a diamond or chilled shot rotary cutter.

In the Baku oil-fields where wells cost as much as £5 a foot to drill, and the strata are mostly soft and spongy, producers never hesitate to cut up or drive aside objects of great size if they defy efforts of recovery after a few weeks, and under the author's directions as much as 200 feet of 10-inch casing has been driven aside and passed in a few weeks. The softness of the Baku strata is exemplified by a case under the author's immediate direction, where months were spent in attempts to recover a large steel tube catcher which was lost in a well through an accident. The work was eventually suspended, but as there was oil present, the well was bailed and gave a surprising production

for a few months before water broke in and flooded the source; but on examining the well there was no trace of the lost instrument, and the well was drilled to a deeper oil source without any signs of its presence.

Many of the simpler forms of fishing tools are of the "bull-dog" description and cannot be released when once

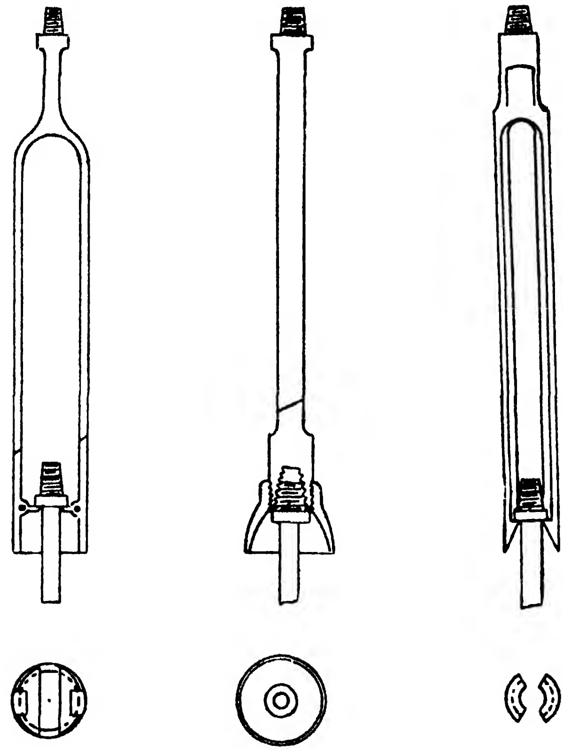

FIG. 60.—VARIETIES OF COLLAR GRABS.

a hold has been secured upon a lost instrument. There is no objection to their employment when the object is known to be free, but if any doubt exists as to its possible withdrawal with the application of reasonable force some type should be chosen that can be released again. Likewise when the freedom of the lost tools is assured some fishing tools

may be lowered on drilling cables or wire ropes, but where their freedom is improbable, they must be attached to and lowered on iron rods, special fishing rods, tubing, or even casing to permit the application of considerable force when a firm hold has been established.

When a joint simply becomes unscrewed and its vertical position is known, an internally tapered screwed box with a bell-mouthed guide can be lowered on rods and screwed up, or if the threads have become damaged by subsequent blows from the detached part of the tools some such form of instrument shown in Fig. 59 with hinged catches may be slipped over the tool. Fig. 60 shows a few common fishing instruments which can be used for such a duty.

Sometimes lost stems and tools which cannot be gripped by any means whatever are milled and screwed by cutters and dies lowered on to the protruding end and rotated by rods or tubing until a firm hold is obtained, whilst again in special cases holes are drilled into embedded instruments and then threaded with a tap before the lost object can be seized and drawn out of its position. In such cases the dies are directed squarely upon the objects by guides, and special fishing rods capable of being rotated both right and left hand without unscrewing should be used.

A good type of fishing-rod largely used in the Baku oil-fields of Russia is illustrated in Fig. 89, where it will be seen that a heavy, loose screwed socket couples two rods, and a tongue and groove prevents the rods turning separately.

Slip sockets constitute the most perfect type of fishing tool invented, as not only do they seize the object with increasing force as greater power is applied, but the best varieties can be released and withdrawn if the object resists a maximum strain of safety. A somewhat simple American type largely used with cable and Canadian tools is shown in Fig. 61. It consists of a strong, well-made steel body which will admit to the interior with little freedom the full-size collar of drilling tools in use, and can be fitted with

guide bowls to suit various sizes of casing. The slips are placed in position in the tool and spread laterally by a small strip of wood about midway. When the slip socket has been lowered over an object the strip of wood is knocked aside and the slips fall into taper recesses corresponding to the taper of the slips and grip the object. The greater the upward force applied to the slip socket the firmer the slip socket grasps the object, and by jarring upwards or jacking, if rods are used, the lost tool is extracted.

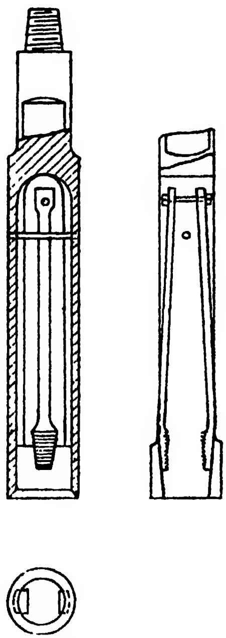

FIG. 61.—SLIP SOCKET.

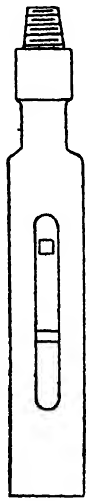

FIG. 62.—COMBINATION SOCKET.
To take hold of Screwed Pin.

A beautifully designed Russian slip socket is that illustrated in Fig. 64, and by its aid almost any tool can be seized and released at will. Such an instrument cannot be manufactured for less than £200, but the cost is amply justified for difficult fishing operations such as occur in the Baku oil-fields.

Broken manilla cables or wire lines can be recovered by

lowering one of the grabs or spears shown in Fig. 49, but if it is desirable to cut a cable or wire line attached to lost tools, a form of cutter is lowered on light rods over the line and jarred until a severance is completed.

Lost bailers and sand pumps can be fished up by

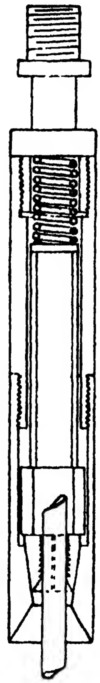

FIG. 63.—AMERICAN SLIP SOCKET.

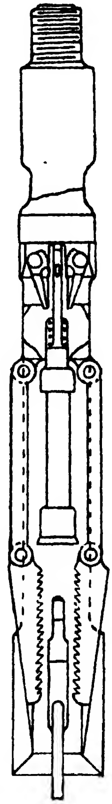

FIG. 64.—RUSSIAN SLIP SOCKET.

lowering some such form of instrument as illustrated in Figs. 67 and 104. If a bailer or sand pump becomes buried in sand and cavings through which it cannot be withdrawn, it is usual to insert flints and stones in the well and drill through it.

Portable Drills.—The expense of dismantling and re-

erecting a derrick and rig at each well has long been a source of concern amongst oil producers, and much ingenuity has been displayed in designing forms of portable rigs which can be moved from one site to another without any expense further than the movement of one machine. The want is particularly felt where wells are completed in several weeks, and as much time is occupied in the transportation and re-

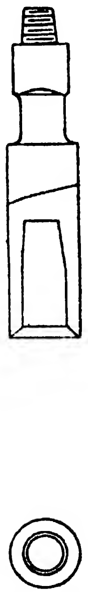

FIG. 65. DRIVE DOWN SOCKET.

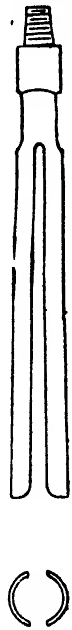

FIG. 66.—SOCKET FOR TAKING FRICTION HOLD OF LOST OBJECT.

FIG. 67.—SAND PUMP GRAB.

erection of the rigs as in the actual drilling, but where nine to eighteen months are occupied in the drilling, as in Russia, Galicia, Roumania, and part of California, and the rig really becomes converted into a workshop, the same need is not felt. In attempts to replace the heavy rough wooden rigs which are commonly used in drilling for carefully designed compact and light machines, the actual part played by such

massive and rough structures has been realised. The elasticity and spring transmitted by the timber frames and heavy foundation timbers is particularly suitable for the class of drilling, and it has been found both in America and in Russia that scientifically manufactured rigs and geared frames have not performed such good work. A drilling rig can only be portable by cutting down weight and introducing rigidity into the structure, and the frame thus loses much of its value. Nevertheless cleverly arranged portable drills are now to be purchased, and they are used to some extent in

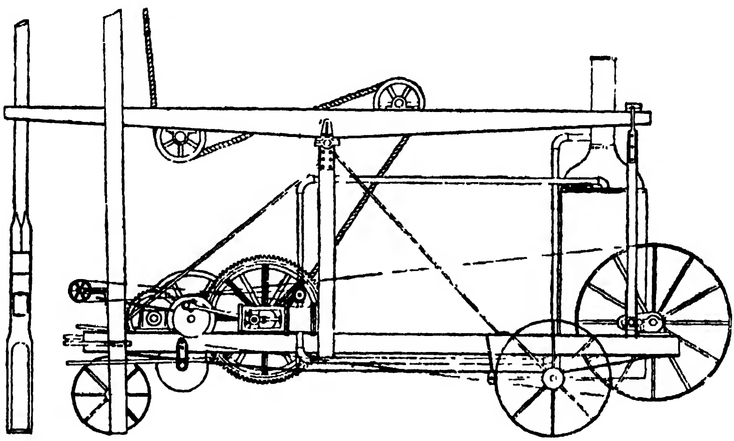

FIG. 68.—COLUMBIA PORTABLE DRILLER.

America for oil drilling when the wells do not exceed a maximum of 1,500 feet in depth, the diameter not excessive, and the strata easy to drill.

Two portable drills have attracted special notice in America, namely, the "Columbia" and "Star," both of which are capable of performing excellent work under suitable conditions. The Columbia driller is constructed on a wrought channel-iron framework at the middle of which are connected two uprights supporting the fulcrum of the walking beam. A vertical channel-iron frame suitably braced forms the equivalent of a derrick, and all the desired motions

are transmitted by a combination of gearing. Figs. 68 and 69 show all the salient features of the drill which can be recommended when such a type is needed. The Keystone rock driller has likewise met with some success for prospecting operations.

Shooting or Torpedoing Wells.—Where petroleum is disseminated amidst hard dolomitic limestones or calcareous sandstones, or where lateral variation of texture in hard rocks leads to the irregular distribution of petroleum through a bed, considerable benefits are often derived by blasting the oil-bearing rock with powerful explosives. The effect of explosions on hard rock not only leads to the destructive shattering of a productive bed, thereby enabling freer movements of the oil, but it sets up a subterranean disturbance amongst the oil and gas enclosed under high pressure in the pores of the rock which continues for a time. Wells sunk to oil-bearing horizons in the Appalachian oil-fields of America often exhibit little or no indications of oil until they have been "shot," after which they frequently flow freely for a while, and give a handsome production. When the oil-bearing stratum is a hard, compact rock the natural infiltration is slow, and a violent explosion will sufficiently crack the bed

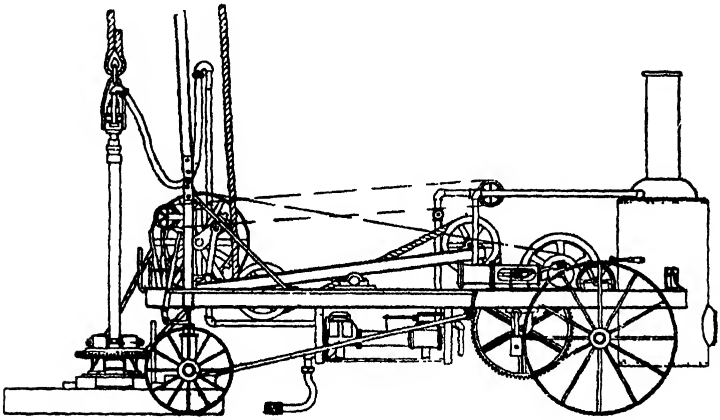

FIG. 69.—PORTABLE DRILL WITH ROTARY ATTACHMENT.

for a wide radius around to allow the containing oil and gas to flow through the numerous fissures to the well. Likewise the fissuring of an unproductive portion of the stratum by an explosion will sometimes cause a connection with productive parts of the same bed in the vicinity. The failure of a small shot to induce a flow of oil may be followed by the successful firing of a more powerful shot, and likewise the periodical "shooting" of a well often causes the production of a well, which has fallen to a nominal amount only, to rise to a high figure.

In soft spongy strata no benefit is derived from torpedoing; indeed, the production of oil may be diminished, as the strata are simply powerfully compressed, and oil inlets may be thereby closed. The following notes, taken from a valuable paper by Mr N. M. Fenneman,* will give a clear idea of the usual objects and methods of "shooting" wells in the Boulder oil-field of Colorado, the arguments in which apply equally elsewhere:—

"All the wells pumped up to the close of the year 1902 have been shot. The amount of nitro-glycerine used in these shots has varied from 10 to 120 quarts. Dynamite charges have been as large as 500 lbs., 70 per cent. nitro-glycerine. The effects of these shots have not been uniformly favourable. The beneficial effects in a few of the best wells have doubtless been responsible for most of the later attempts. It is by no means certain as yet that this practice will be universal in this field. At least one well has recently begun pumping without being shot, and the owners have no immediate intention of shooting. The fact that the flow of some wells has decreased since the shooting will lead to greater caution, and it is to be hoped that it will lead to a more careful study of the conditions present in each well.

"The beneficial or harmful effects of a shot must depend largely upon the texture of the stratum yielding the oil, for

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* "Contributions to Economic Geology, 1902," U.S. Geological Survey.

it seems to be true that some shales are compacted rather than shattered by the explosion. For this reason, shooting is not practised in the Florence field, which, of all the older oil districts, the Boulder field most resembles. Owing to the difference in texture of the various beds yielding oil in the Boulder field it is but reasonable to expect that the same shot which would prove beneficial to one well would be ruinous to another. On this account, if on no other, the texture and composition of the oil strata should be carefully studied by methods far more discriminating than the super ficial ones now used.

"A second reason for injurious effects from shooting lies in uncertainty about the exact depth of the sand which it is intended to shatter. Measurements of depths by steel tape are indeed becoming more common, but in a considerable number of wells the depths of all formations are known only by cable measurement. Even in wells but recently sunk it is not uncommon that the stated depths of important sands are thus liable to errors of 25 to 50 feet.

"The shooting of oil wells with nitro-glycerine is a dangerous operation unless the greatest care is exercised in the preparations for firing. Premature ignition is not by any means unknown, when, besides the ruin of a well, the operators may lose their lives. Nitro-glycerine is also an explosive which does not fire with the certainty of many other kinds, and in the event of a failure some discretion is needed in deciding upon the best way of firing the torpedo or disposing of it. The nitro-glycerine in quantities of from 20 to 100 quarts is usually poured into metal cylinders at the mouth of the well, and the upper container is fitted with a firing head, which, on receiving a blow, fires a percussion cap immersed in a small charge of nitro-glycerine, which in turn explodes the torpedo. The blow is usually administered to the firing head by a 'go-devil,' a piece of cast iron with wings to guide it fairly on the cap of the firing head. In the event of a shot not exploding, a small vessel of nitro-glycerine is

lowered with a time fuse attached to produce ignition of the charge when it has reached the bottom of the well. The firing of the charge explodes the former.

"The possible injuries from a shot at the wrong place may be readily seen from the following considerations:—Given a porous rock saturated with oil which is under a certain pressure. This rock is now, for the sole reason that it has no outlet in any other direction, being surrounded (as in this field) by impervious rocks. This well is now shot in such a way as to rupture the impervious rocks which have surrounded the oil sand. The oil may now leave the sand by other openings besides the well, and may thus be dissipated in other porous beds and the well may be ruined. Such an effect may be produced even by shooting at the proper depth if the charge employed be too heavy. In one instance a well was shot at 740 feet with 500 lbs. of dynamite, 60 per cent. nitro-glycerine. The formation above the sand was a uniform dense shale. A good quality of sandstone was blown from the hole in chunks reaching a maximum of 14 lbs. The shale was ruptured to the surface. Open cracks of an inch or more extended for some rods from the well. Presumably, also, cracks reached a considerable depth below the sand which was to be shattered.

"It cannot be too carefully borne in mind that the one object in shooting is to shatter the rock which carries the oil and that only. With this object in view, it is plain that intelligent and discriminating shooting must depend upon information which the following questions may suggest:—Is the texture of the oil stratum such as to give promise that it will be shattered rather than compacted? What is the exact depth of its top (and bottom if drilled through)? How much of a shot will the overlying rocks bear without giving other outlets to the oil? This last question is one of great importance in this field. It is needless to say that such questions can be answered only by a carefully kept log and close study of samples, not only of oil sands, but of all strata, in order to

properly forecast their behaviour under the influence of a shot."

Contract Drilling.—Wherever reputable contractors can be engaged or qualified drillers can be induced to accept contract work the policy should be adopted. In drilling wells so much depends upon the actual operator, over whom little direct supervision is possible, that it is advisable to directly interest them in the work. There are objections to the pursuance of such a course, for there is a disposition in contractors to disregard the aims of the proprietor to find oil and confine their energies solely to the drilling of a maximum depth within a minimum period, and oil sources may be passed through without being reported unless a close watch is kept. Contractors also do not favour the temporary suspension of drilling to undertake water exclusion measures, during which period they only receive, as a rule, a nominal daily sum to little more than cover expenses, consequently there is an inclination to conceal the existence of water sources which, if they do not hide the presence of oil, may subsequently cause the permanent injury of a producing well. A conscientious boring contractor with his employer's interests at heart will not only faithfully carry out his contract but advise generally on the course to pursue at each juncture; but it is more satisfactory for both parties if the producer appoints independent inspectors to overlook the drilling.

The form of contract varies in different oil-fields. Sometimes the contractor has to find everything, whilst at other times he is given his power, fuel, and water, or even all the necessary drilling machinery as well. The following is a translation of the usual form of contract for drilling the wells in the Baku oil-fields, which is as full as any contract made anywhere, and foresees almost every contingency connected with drilling oil wells :—

1. The Firm has given over to the Boring Contractor, and the latter has taken over for boring, well No.   on Plot No.   . Not later than   the Firm must give Contractor a correctly built

and fully equipped derrick, as detailed in Clause 2 of this Agreement, and the Contractor must, within thirty days of taking over the boring, commence work and continue it night and day with his foreman, workmen, and instruments, and with his own boring rig, until reaching an oil source which shall be considered by the Firm sufficient for exploitation, but not necessarily deeper than 250 sagens (1,750 feet).

2. The Firm supplies a derrick covered with some fireproof substance with all appliances, a completed shaft with guide and floor, a completed foundation for boring rig made according to Contractor's instructions, a bailing pulley, a steam engine or electric motor of not less than 60 H.P., with sufficient energy necessary to run the same, four electric lamps—one being portable, convenient roadway to the derrick, a bridge at the side door of the derrick, and also deliver to the well good quality iron casing of not less than ¼ inch thickness riveted in columns of two, three, or four tubes, according to the desire of the Contractor, a double template for testing the tubes, rivets, clay, cement, and hard stone for stamping down shaft and well, also water, which must be delivered in requisite quantity by means of the property pumps to the mouth of the well. For trial bailing the Firm supplies rope, belt, and bailer, and for cementing all necessary materials and appliances. The Contractor has use of all the above, and is supplied with them whenever required, and for all the time work is carried on in the well.

Note.—Care of the engine, oiling and repairs of same, also keeping in repair derrick, electric light, and also fire-extinguishing apparatus, must be performed by the Firm.

3. Boring must be commenced with shaft tubes of 32 inches diameter, and continued with tubes of 30, 28, 26, 24, 22, 20, 18, 16 inches diameter in such a manner that the mean depth of each column passing into the ground shall not be less than 30 sagens (210 feet), excluding from the total depth the depth of the shaft column, safety column, and those columns stopped on account of the non-fulfilment on the part of the Firm of the conditions set out in Clause 2 of this Agreement, and those columns stopped on account of fire, on account of the sudden disappearance of liquid in the well, or on account of the entry of cement into the well. Columns of casing stopped for the above reasons are not taken into account when making up the mean depth bored, if, in such cases, the column has passed down less than 30 sagens. If, on delivery of the well, it should appear that the Contractor has not carried out this obligation, and has lowered more tubes than necessary in order to drill 30 sagens with each column, then the extra number of columns of tubes will be for account of the Contractor at cost price. The Contractor is freed from above obligation if columns of tubes are stopped or pressed into clay at the request of the Firm, or become stopped on account of trial bailing or fountains.

4. If in the course of boring, owing to the fault of the Contractor, the well should become so damaged that further boring is impossible, and the Contractor finds it impossible to repair same, then the Contractor must transfer the derrick to another place on the same property, and

without charge bore there another well with his own casings of the same diameters to the depth of the spoilt well. At the same time the Contractor has the right at his own cost to withdraw casings from the damaged well, and use them as he may see fit. If, however, the well has become damaged on account of trial bailing, a fountain, fire, appearance of gas, sudden disappearance of liquid, cementation or pressing column down at request of the Firm, and similar reasons, then for the results of such the Contractor does not answer, and the repair of the well will take place for account of the Firm, and by special agreement on both sides.

5. On demand by the Firm, the Contractor must carry out the following :—

(*a.*) By means of a centring apparatus to test the well for verticality up to a depth of 140 feet, and the well is considered vertical if the displacement of the column to one side at 140 feet does not exceed 1 inch.

(*b.*) Before proceeding to trial bail after cementing, and also before pressing down a column, to lower a column of four tubes 2 inches less in diameter than the last casing, and the well to be considered in order if this column passes to the shoe.

(*c.*) To cut out columns at depths determined by the Firm, not, however, at a lower depth than 35 feet above the depth of the previous shoe.

(*d.*) To stop or press down a column of tubes at any depth, to carry out cementation, trial bailing, cleaning plug, and other work, as may be determined by the Firm, and at their responsibility.

(*e.*) To measure the length of the column with shoe fork.

6. For every sagen drilled up to 100 sagens boring is carried out at the basis price of 100 roubles, thereupon for every additional 10 sagens above 100 sagens bored to the basis price is added 10 roubles per sagen, *i.e.*, the cost per sagen for boring from 100 to 110 sagens is 110 roubles, for boring from 110 to 120 sagens is 120 roubles, and so on. Measurement of depth takes place from the floor of the derrick to the bottom of the well. (A sagen is 7 feet ; a rouble 2 shillings.)

7. For all work not connected with actual drilling of the well, such as ramming down and strengthening the shaft, making and cleaning artificial plug, cementing, trial bailing, cleaning plug, and moving columns after trial bailing, fishing for and taking out instruments lost while carrying out any of this special work, also taking out instruments seized by cement, and other such work with the exception of cutting up casing, the Firm pays the Contractor 40 roubles (£4. 5s.) per day.

8. If any column of tubes stops on account of trial bailing, fountain, fire, entry of cement into the well, or on account of non-fulfilment by the Firm of Clause 2 of this Agreement, or if any column of tubes has been stopped at the request of the Firm, and if the columns stopped for any of the above reasons have been drilled into the ground less than 280 feet, then the lowering of the next column of tubes to the shoe

of the previous column shall be for account of the Firm at 4 roubles per sagen of tubes lowered, such charge being also made for lowering safety column of tubes. In all other cases the Contractor lowers columns of tubes at his own expense.

9. Cutting and taking out columns of tubes is carried out at the price of 4 roubles per sagen of tubes withdrawn, such tubes being unriveted in columns of four tubes each. If after several attempts at cutting, the column comes away at the top cut, the remaining pieces of cut column have to be raised by means of tube catcher and fishing rods, then this work will be carried out by special agreement on both sides.

10. For all stoppages of work the offending party shall pay the other party 40 roubles per day. The Contractor shall receive this 40 roubles per day also if the stoppage has occurred on account of a fountain in the neighbourhood. For stoppages and results of such stoppages caused by act of God, strikes of workmen, national disturbances, boiler explosions, fire, &c., both sides are freed from any responsibility, but in case of fire the Contractor has the right to remove his property from the derrick until it shall have become possible to resume the interrupted work.

11. Settlement of accounts between both parties shall take place in cash once a month, not later than the 15th day of the month, for work carried out by the Contractor during the previous month.

12. The Contractor has the right to stop work and remove his property from the well without incurring any responsibility for such stoppage and the consequences thereof in the following cases :—

(*a.*) On reaching the limit depth of 250 sagens, should no additional agreement have been arrived at by the parties for the continuation of the work.

(*b.*) On final stoppage of 8-inch column of tubes.

(*c.*) On stoppage of work through the fault of the Firm for thirty days consecutively.

(*d.*) After two months trial bailing and cleaning cork, should no further deepening of the well take place after this period.

(*e.*) On non-payment at the time mentioned in Clause 11 of sums due to the Contractor.

13. The Contractor takes full responsibility (criminal and civil) for all accidents occurring to his workmen in the course of carrying out the work, as laid down in this Agreement, and must fulfil all legal demands of the Authorities having connection generally with such work, for which he must prepare a special signed document embodying the above in legal form for handing in to the Second Caucasian District Mining Department.

14. The Contractor must keep daily records of boring work and hand same in the form of daily boring reports to the Firm's property office, and must allow the Firm's representative into the derrick at any time to supervise and check the work. A boring report to which no objection has been received within three days shall be considered accepted, and cannot be disputed after the lapse of the above-mentioned three days.

All orders, declarations, and objections of the Firm to the Contractor must be in writing.

15. In case a stoppage of work for a period of thirty days consecutively has taken place through the fault of the Contractor, then the Firm, having first completed payment for work performed, may refuse further work to the Contractor, and may consider the Agreement cancelled without further consequences for either side.

16. All disputes and misunderstandings of a technical nature arising out of this Agreement shall be settled (within one month from date of declaration by one of the parties giving notice of his desire to that effect) by three experts in Baku, each party electing one expert, and these two experts electing a third.

17. On account of the indeterminate nature of the sums to be paid under this Agreement, the latter is stamped with a bill stamp value 1.25 roubles on condition that, the regular payments being made each month, both parties will pay the bill tax equally.

In the American oil-fields the contractor is sometimes furnished with a drilling rig, casing, and power, but must himself find the tools and be responsible for fuel, water, drilling cables, sand lines, and small accessories. The following agreement is a typical form used by one of the largest oil-producing companies in the eastern oil-fields of the United States:—

THIS AGREEMENT, made this day of A.D. 18 , between of parties of the first part, and the OIL COMPANY, party of the second part.

WITNESSETH, That the said parties of the first part have covenanted and agreed with the said party of the second part, its successors and assigns, that said parties of the first part will drill for said party of the second part a certain well for the purpose of obtaining petroleum oil or natural gas, to be known as WELL No. on the farm of township county .

The material, machinery, and appliances necessary for drilling and completing said well shall be furnished, and the work of drilling the same shall be done in the manner hereinafter specified, viz.:—

A complete carpenter's rig of good quality (including wooden conductor) to be furnished by the party of the second part, and all repairs on same while the well is being drilled shall be made by and at the expense of said parties of the first part.

All casing to be furnished by party of the second part.

Boiler, engine, belt, bull rope, steam and water pipe, and connections to be furnished at the well by party of the second part.

The expense of fitting up and connecting same to be borne by parties of the first part.

Fuel to be furnished at expense of the parties of the first part.

Water to be furnished at the expense of the parties of the first part.

Oil saver and steel measuring line at expense of the party of the first part.

All machinery, material, and appliances furnished by said parties of the second part shall, at the completion or abandonment of said well, be returned to said party of the second part in as good condition as when received by said parties of the first part, ordinary wear and the action of the elements alone excepted.

The said parties of the first part further agree to pay all expenses and furnish everything necessary to drill and complete said well, except the articles and appliances herein specifically mentioned to be furnished by the party of the second part.

The said well, unless sooner abandoned by direction of the party of the second part, is to be drilled to 2,000 feet, the consideration for which shall be two dollars per foot.

All fresh water shall be cased off with a casing of a diameter of not less than inches, and all salt water cased off with casing of a diameter of not less than inches.

The diameter of the well when completed shall not be less than inches.

The outside strings of casing, viz., the inch and inch, shall be pulled at the expense of the party of the second part.

When the said well reaches the oil or gas-bearing sand, the method of drilling through the same shall be under the direction of said party of the second part, or its agent in charge of the farm or lease, and if oil or gas is found in sufficient quantities to endanger the rig and material by fire from the boiler, then said parties of the first part shall, without delay, and at second party's own expense, move the boiler to a safe distance from the well. All pipe fittings made necessary by such removal to be furnished by the said party of the second part.

When completed, unless prevented by too great a volume of gas or oil, the well shall be thoroughly "bailed" and "sand pumped" by the said parties of the first part, until all drillings and sediment are removed therefrom and the well thoroughly cleaned.

The parties of the first part shall carefully examine all machinery, casing, and other appliances to be furnished for said well by the party of the second part, and if any defect be found therein sufficient to make the use of such machinery, casing, or other appliance unsafe, shall immediately notify the party of the second part of such defect or defects, and the party of the second part shall at once replace the article so found defective with a good and safe one; but if the parties of the first part shall not make such examination, or shall not report any defects in said machinery, casing, or other appliance, they shall be deemed to have assumed all risks and all responsibility for any mishap which may occur in the drilling of said well by reason of a failure in such machinery, casing, or other appliance.

No part of the contract price above mentioned shall in any event be

paid until said well shall be completed to the depth above required, and delivered to the party of the second part in thorough good order, free and clear of all obstructions.

The parties of the first part agree to begin the drilling of said well within thirty days from   and prosecute the work actively and continuously (Sundays excepted) to completion.

IT IS FURTHER AGREED, That time shall be of the essence of this contract, and that in case the parties of the first part shall neglect or discontinue the work of drilling said well for the space of ten days, such neglect or discontinuance shall of itself be a forfeiture of all rights and claims of the parties of the first part under this agreement without any notice or demand by the party of the second part. The party of the second part shall have the right at any time after such forfeiture to take possession of said well, discontinue the drilling thereof, and at its pleasure dismantle or abandon the same without liability to the parties of the first part for any portion of the contract price above mentioned. The party of the second part shall also have the right at any time after such forfeiture as above mentioned, if it so elects, to take possession of said well and all the ropes, tools, and appliances thereat of the parties of the first part, and drill said well to completion. In case it shall succeed in completing said well, the cost of such completion without any allowance to said parties of the first part for the use of the said ropes, tools, and appliances, shall be deducted from the contract price above mentioned, and the balance, if any, paid to the parties of the first part; but if said party of the second part should not succeed in completing said well, it shall not be liable to the parties of the first part in any sum whatever, and shall return said tools, ropes, and appliances to the parties of the first part in as good order as when received, natural wear and tear and accidental loss or breakage excepted.

IN WITNESS WHEREOF, the parties of the first part have hereunto set their hands and seals, and the party of the second part has caused these presents to be signed by its representative, the date first above written.

CHAPTER VI.

Casing or Lining Tubes for Oil Wells, and Appliances Employed in Connection with its Insertion, Extraction, and Repairs.

Objects of Casing—Types of Well Casing—Casing Shoes—Casing Elevators or Clamps—Cutting and Removing Casing—Recovering Lost Casing—Repairing Damaged Casing.

Objects of Casing.—When a well is sunk through a fairly horizontal and compact series of strata, or through a rocky formation, drilling may be continued for hundreds of feet, and even to 1,500 feet or more, without material from the sides falling into the well, or "caving" as it is usually termed in oil-field phraseology. Generally, however, the strata through which drilling is conducted are inclined at an angle, and the beds are not only laminated, but they may be fractured and fissured, and may contain large quantities of water stored in their interstices. So fragile or disturbed are some strata capping or intervening between oil-bearing sands that but a few feet can be drilled without the sides of the hole crumbling down and filling up the well as fast as it is drilled. When caving is so serious as to endanger the loss of the tools, or to fall in nearly as fast as material is removed, the well has to be lined with tubes in order to sustain the sides and prevent the drilling cable or rods from striking the sides of the hole and further loosening the strata. The best kind of casing for a particular district is dependent upon circumstances, of which the following points largely influence the choice:—

(1.) Diameter and depth of wells.

(2.) Character of strata.

(3.) The presence of water which has to be excluded.

When deep wells exceeding 12 or 14 inches in diameter have

to be lined, screwed casing can rarely be used on account of its prohibitive high price, and in such fields as those of Baku and Roumania riveted casing is chiefly employed for the large sizes. When the strata are of a very caving nature a stronger casing is needed than where the formation is firm and not

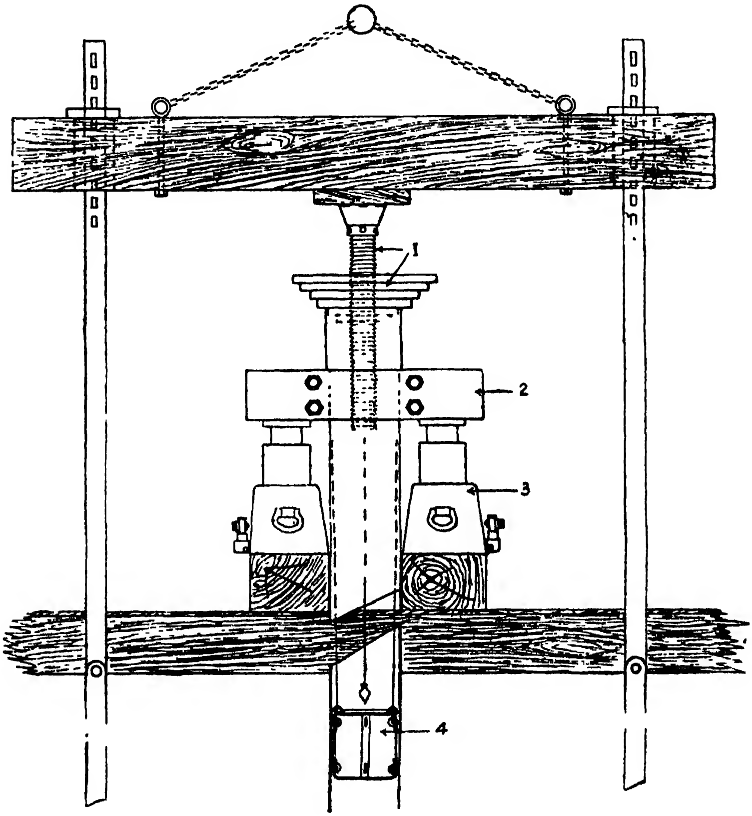


FIG. 70.—METHOD OF PRESSING TUBES, JACKING TUBES UP, AND CENTRING ARRANGEMENT.

1. Screw and Plate.
2. Casing Clamps.
3. Hydraulic Jacks.
4. Centring Device.

very liable to cave or slip. If conditions demand the driving of casing through certain beds some descriptions of casing are unsuitable, and when water has to be excluded good screwed casing must be used to ensure watertight joints, unless a pro-

cess of cementation is undertaken. In some oil-fields a single column of casing may be continued to almost any desired practicable depth, but more generally the distance is limited to a few hundred feet, and deeper drilling can only be continued with a reduced size of drill and lining with a smaller size of casing.

When the wells are deep and the strata are of a caving description, the starting size has to be considerably larger than the ultimate desired diameter, as each time a column of casing stops a smaller one has to be inserted when drilling is continued. In many of the American oil-fields a commencing diameter of 12 to 14 inches is ample to give a completed diameter of $4\frac{1}{2}$ or 6 inches at 2,000 feet, which allows the lowering of a deep well pump, but in the Russian and Roumanian oil-fields, where the strata cave badly, and the oil has to be bailed, a commencing diameter of 30 to 36 inches is necessary to assure a completed diameter of 12 to 16 inches at 2,000 feet. In all cases it is desirable to use casing which permits of a minimum loss of diameter at each reduction of size. In California a common practice is to use $12\frac{1}{2}$, 10, $8\frac{1}{4}$, $6\frac{5}{8}$, and $5\frac{3}{16}$ inches nominal internal diameter casing, each diminishing size passing freely through the larger size. This gives a reduction in diameter of $7\frac{5}{16}$ inches in four columns, an average of 1.82 inches for each string. In oil-fields where large sized casing is used each column is reduced by 2 inches.

Types of Well Casing—*Screwed Casing.*—When wells do not exceed 10 to 12 inches in diameter, lapwelded screwed tubing is almost universally employed for lining the wells. In the United States of America the casing is always manufactured from mild steel, but in England iron is often employed by the large tube manufacturers. There are advantages to be claimed for each material. Steel is harder than iron, and will better withstand the rough treatment to which it is often subjected in oil-fields; on the other hand, steel is much more readily attacked by the salt and acid waters which almost invariably occur in the strata amidst oil

formations. When screwing up *iron* casing very firmly too much pressure must not be applied to the ordinary pipe wrenches, otherwise the tubes will be dented. American casing is generally made in longer lengths than British, an advantage in oil-field work, as much time is thereby saved in inserting a long column in a well. With the exception of a proportion of short lengths the tubes should be as long as possible. American lengths are from 20 to 25 feet, British from 16 to 22 feet.

During recent years weldless tubes by the Mannesmann process have been introduced with success, the advantages of a weldless tube being obvious, whilst the process also admits

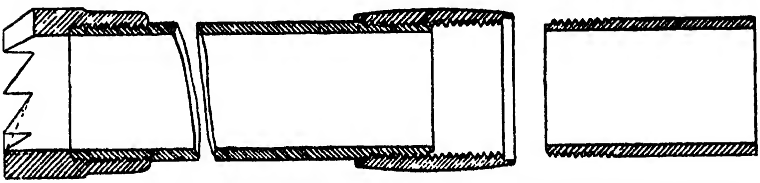


FIG. 71.—COMMON WELL CASING FITTED WITH ROTARY CUTTING SHOE.

of tubes being made up to 35 to 40 feet long. There are several varieties of screwed casing described as follows:—

Sleeve, Collared, or Socketed Casing.—The sleeve coupling, collared or socketed joint for standard well casing, has, according to American practice, the following dimensions:—

PARTICULARS OF ORDINARY AMERICAN CASING.

Nominal Internal Diameter in Inches.	External Diameter in Inches.	Weight per Foot in Lbs.	Thickness in Inches.	Threads per Inch.	Outside Diameter of Collar in Inches.
$12\frac{1}{2}$	13	33.78	.271	$11\frac{1}{2}$	14
$10\frac{5}{8}$	11	26.72	.203	$11\frac{1}{2}$	$11\frac{7}{8}$
$8\frac{1}{4}$	$8\frac{5}{8}$	24.38	.271	8	$9\frac{3}{8}$
$6\frac{5}{8}$	7	17.51	.248	10	$7\frac{11}{16}$
$5\frac{3}{16}$	$5\frac{1}{2}$	12.49	.229	$11\frac{1}{2}$	$6\frac{1}{16}$

The threads are cut with a slight taper, and when screwed up firmly the ends of the tubes should nearly butt. The end threads should be turned down to allow the tubes to be screwed together easily and to prevent burring of the end

threads. Likewise the collars or sleeves are slightly recessed on the inside for the same reasons, and bevelled on the outside edges, but for transport, iron protective rings must be made to screw into the collar and on to the free screwed end to prevent damage in transit. This casing is widely used and will stand a reasonable amount of driving if judiciously applied, and for pioneer work this should be chosen in preference to other kinds. British manufacturers who do not work so much to fixed standards will modify the dimensions to suit any particular conditions.

Some 10 to 12 inch collared steel casing specially made by the Nikopol-Mariopole Works for the Russian oil-fields has the following dimensions:—

	10-inch.	12-inch.
	Inches.	Inches.
Thickness of casing - - - - - -	0.3	0.3
" of collar - - - - - -	0.75	0.75
Length of collar - - - - - -	12.02	14.00
" of screwed portion each end - -	4.875	5.9
" of recessed collar - - -	1.0	1.0

There are six and eight threads per inch, and they are cut slightly tapered to allow tubes to butt in centre, and the collars are tapered slightly at each end externally.

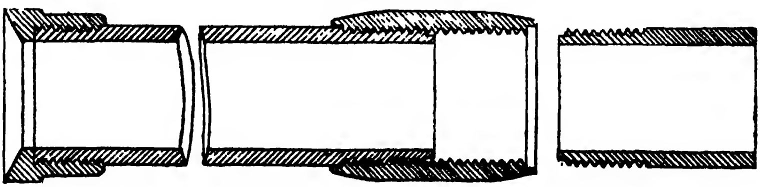


FIG. 72.—HEAVY DRIVE PIPE FITTED WITH DRIVING SHOE.

Drive Pipe.—When heavy driving has to be resorted to in drilling, a thicker type of casing is usually employed, specially made to withstand heavy blows. The threads are parallel and the joints are made to butt, and it is usual, owing to the greater thickness of metal, to have eight threads per

inch. The dimensions of standard American drive pipe are as follows:—

AMERICAN DRIVE PIPE.

Nominal Internal Diameter in Inches.	External Diameter in Inches.	Weight per Foot in Lbs	Thickness in Inches.	Threads per Inch.	Outside Diameter of Collar in Inches.
6	$6\frac{5}{8}$	18.76	.280	8	$7\frac{1}{2}$
8	$8\frac{5}{8}$	28.18	.322	8	$9\frac{9}{16}$
10	$10\frac{3}{4}$	40.06	.366	8	$11\frac{7}{8}$
12	$12\frac{3}{4}$	49.00	.375	8	$13\frac{7}{8}$

Inserted Jointed Casing.—When no driving is necessary and it has been ascertained that nothing is needed beyond the insertion of a light tube to sustain the walls of the bore-

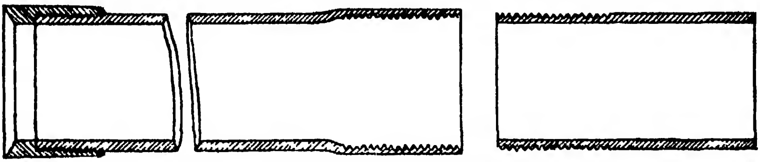


FIG. 73.—INSERTED JOINTED CASING WITH SHOE.

hole, inserted jointed casing, illustrated in Fig. 73, can be cheaply and advantageously employed. One end of the tube is simply swelled to take the unswelled part, but it sometimes takes a modified form as swelled and cressed casing (Fig. 74),

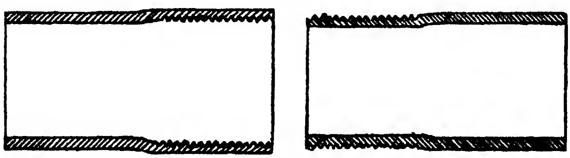


FIG. 74. SWELLED AND CRESSED CASING.

its construction consisting in slightly swelling one end and reducing the other for a distance equal to the length of a collar, the combined swelling and reducing allowing slightly tapering threads of ordinary dimensions to be cut. By this means the extra diameter inseparable from a collared joint

is diminished, the increased size necessitated by the joint being distributed internally and externally equally. The American inserted jointed casing is screwed externally without reduction, whilst the internally screwed portion is alone expanded. The obvious disadvantage of this type of casing is the difficulty of swelling and rescrewing new ends when the threads become damaged, although by using this type

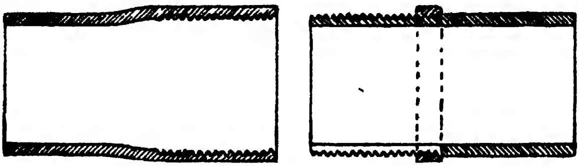


FIG. 75.—INSERTED JOINTED CASING WITH DRIVING RING.

of casing the well need only be reduced by 1¼ to 1½ inches each time a new column is inserted. To enable this casing to be lightly driven past obstacles, and so greatly increase its utility, a faced ring is sometimes screwed on the externally threaded end, as in Fig. 75, against which the swelled end butts when screwed up. The whole of the force when driving is thus thrown upon the ring which screws firmly to the end of the threads preventing the swelled end from bursting as may be the case when no such ring is fixed. Actual tests showed an increased compressive strength of nearly 50 per

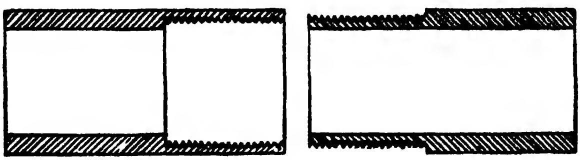


FIG. 76.—FLUSH JOINTED CASING.

cent. over the same casing without a ring. This casing also enables the operator to use casing elevators instead of clamps, thus hastening the process of insertion and withdrawal from a well.

Flush Jointed Casing.—Flush jointed casing, illustrated in Fig. 76, is made by turning down and screwing and boring out

and screwing the ends of parallel tubes so that a flush joint is left both internally and externally. The threads have to be fine to reduce to a minimum the cutting away of metal, and the casing is always very weak and requires care in handling. Flush jointed casing is sometimes used when it is very desirable to reduce the loss of diameter at each change of casing to a minimum, and when specially difficult ground such as sands have to be passed where collars or external projections would greatly impede the movement of a column. When screwed to butt the casing is watertight and can be driven, but any deflection from the vertical will generally result in fracture at the weak point at the base of the threads. The casing is very rarely employed for oil-field operations.

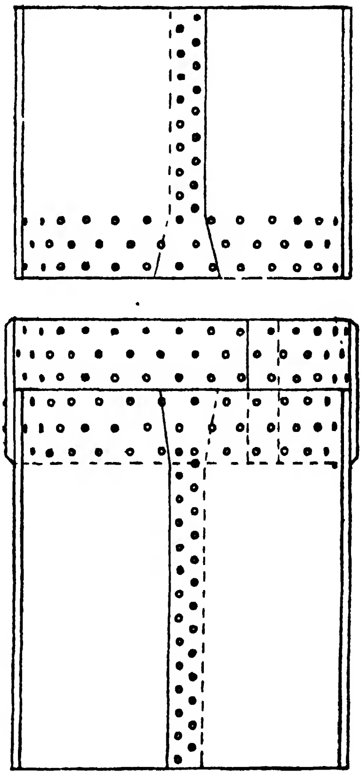


FIG. 77.—COMMON RIVETED CASING.

Riveted Casing. — Where lining tubes of large diameter are required it is customary to use riveted sheet-iron casing. The manufacture of this type of casing has been largely conducted in Roumania and perfected in the Caucasian oil-fields of Russia where from 40,000 to 50,000 tons are annually used in sizes between 36 inches and 10 inches. Riveted casing has been made as small as 6 inches in the Russian fields when all screwed tubes had to be imported against a heavy import duty, but more generally sizes below 12 inches are now of the screwed variety, and in many cases a

special type of screwed casing is used running up to 14 inches in diameter.

Russian casing is made by cutting sheets of $\frac{3}{16}$ to $\frac{5}{16}$ inch iron into the requisite size, and after punching and countersinking the holes on the inner side and rolling into shape, riveting up the vertical lap-jointed seams by a double or treble row of rivets placed zigzag. The tubes are usually made in lengths of 4 feet 8 inches (2 arsheens), and at one extremity a rolled strip of similar iron, 9 to 18 inches wide, is attached by riveting to form a collar. Each end of the tube is punched or drilled with a treble or quadruple row of holes set out from a template before rolling, so that the tubes shall be absolutely interchangeable, and the collars are also punched or drilled to suit the same holes. Sometimes the edges of the plates are faced where the tubes will butt on connecting up.

When a column of riveted tubes is being lowered inside a larger one, four tubes are generally connected together to make 18 feet 8 inch lengths (8 arsheens) at the works and supplied to the well in that state until the bottom is reached and drilling recommences. The reasons for continuing the practice of making such short tubes in the Baku oil-fields are: (1) the need for keeping the lining tubes close to the drilling tools to prevent caving; (2) the desirability of keeping the collars near together and thus, in repeatedly putting the column in motion, keeping the bore-hole the size of the collar, as it is claimed that long distances between individual collars endanger the freedom of the tubes by cavings between the collars which arrest the further movement of the column. Before insertion, the joints of the riveted tubes are well caulked to make them watertight.

The tubes are riveted in place in the well by means of a riveting machine, as shown in Fig. 78. The new tube is placed in position in the socket of the lower tube preparatory to connecting up, all the holes having been made to correspond by using a drift. The riveting machine consists of a stiff cross-bar from which are suspended by light iron

rods two cast-iron segment blocks of the same sweep on the outer edge as the casing, and provided with taper grooves on the inside between which a corresponding taper wedge block slides. This latter wedge block is connected by a rod

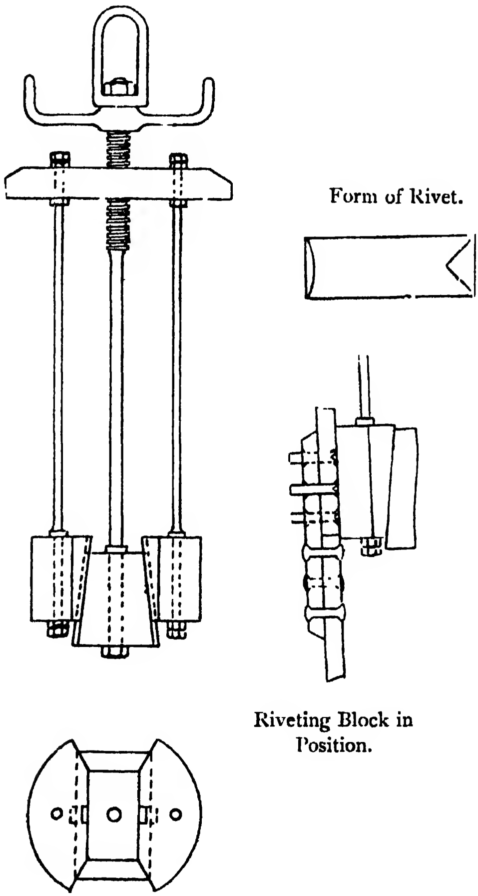


FIG. 78.—RIVETING BLOCK FOR RIVETING UP CASING.

to the surface cross-bar into which it is screwed with a square thread, the lower end of the rod rotating freely in the wedge block. The suspension rods are just the correct length to allow the cast-iron segment blocks to lie against the collar to be riveted, and by screwing the central spindle in the cross-

bar the wedge block is drawn upwards, forcing the segments outwards against the inner side of the casing. A few blows from a hammer on the casing when touching the iron blocks ensures perfect contact at all points and riveting may be commenced.

The rivets are specially made from soft iron for the work, as, of course, under oil-field conditions they have to be hammered cold; and at one end they have a V-shaped recess which leaves a fine circular edge. When the rivets are driven against the block the fine rim of the iron expands and fills the internally countersunk hole, whilst simultaneously the spare metal on the outside is being hammered into a head by the riveters.

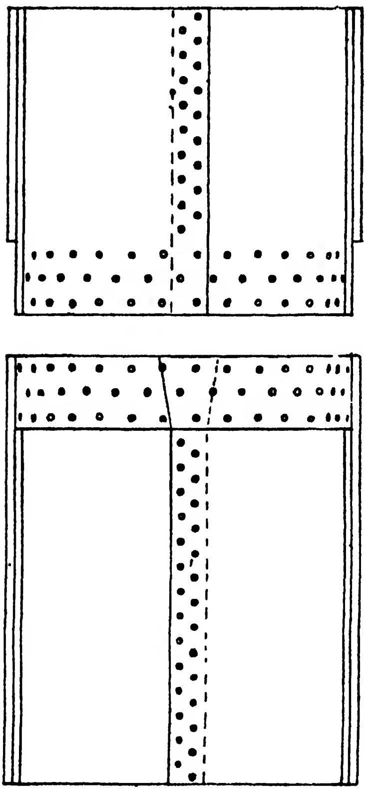


FIG. 79.—DOUBLE RIVETED CASING.

When all the holes are riveted up on the blocks, the central spindle is released and the blocks turned to a new position, when the operation is repeated, two men usually being employed on each side of the blocks at the same time. If the tubes are connected in longer lengths the suspension rods and central spindle are replaced by longer ones, and for other sizes of casing suitable cast-iron segment blocks are attached to the apparatus.

Table XXXVIII. gives the particulars of riveted lining tubes with 12-inch collars made of $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ inch iron, as used in the Russian oil-fields.

TABLE XXXVIII.—FULL PARTICULARS OF RIVETED LINING TUBES WITH 12-INCH COLLARS.

Diam. of Tube.	Size of Iron for Tube.	Size of Iron for Collar.	Tube. Weight in Poods.*			Collar. Weight in Poods.			Total. Weight in Poods.			Total Weight in Poods per Sagen.		
			$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.
8	56×29	12× 32	2.3	3.1	3.9	0.55	0.73	0.91	2.9	3.8	4.9	4.3	5.7	7.3
10	56×35	12× 38	2.9	3.7	4.7	0.65	0.88	1.10	3.6	4.6	5.8	5.4	6.9	8.7
12	56×42	12× 44	3.4	4.5	5.7	0.76	1.01	1.26	4.2	5.5	7.0	6.3	8.2	10.5
14	56×48	12× 51	3.9	5.2	6.5	0.88	1.17	1.43	4.8	6.4	7.9	7.2	9.6	11.8
16	56×54	12× 57	4.4	5.8	7.2	0.99	1.32	1.65	5.4	7.1	9.0	8.1	10.6	13.5
18	56×60	12× 63	4.9	6.5	8.1	1.09	1.50	1.84	6.0	8.0	9.9	9.0	12.0	14.8
20	56×67	12× 70	5.4	7.1	9.0	1.20	1.60	2.0	6.6	8.8	11.0	9.9	13.2	16.5
22	56×73	12× 76	5.9	7.9	9.8	1.29	1.70	2.1	7.2	9.6	11.9	10.8	14.4	17.8
24	56×79	12× 83	6.4	8.5	10.7	1.44	1.90	2.4	7.8	10.4	13.1	11.7	15.6	19.6
26	56×86	12× 89	7.0	9.3	11.6	1.53	2.00	2.6	8.5	11.3	14.1	12.7	16.9	21.1
28	56×92	12× 95	7.4	10.0	12.4	1.65	2.2	2.8	9.0	12.2	15.2	13.5	18.3	22.8
30	56×98	12×101	7.9	10.6	13.2	1.74	2.4	2.9	9.6	13.0	16.1	14.4	19.5	24.1

* 1 pood = 36 English pounds.

Sometimes "double" riveted casing is made which really consists of a tube and collar in which the latter is equal in length to the former, but when riveting the two tubes together one is made to extend about 12 to 16 inches beyond the other to form a collar to which the next tube can be attached. Table XXXIX. gives particulars of the sizes of iron, weights, &c., of such double tubes.

TABLE XXXIX.—PARTICULARS OF DOUBLE RIVETED CASING.

(All weights in poods.)

Diam. of Tube.	Size of Iron for Outside Tube.	Size of Iron for Inside Tube.	Weight of Outside Tube.		Weight of Inside Tube.		Total Weight.		Weight per Sagen.	
			$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.
Inches.	Inches.	Inches.								
12	56 × 43	56 × 41	3.5	4.6	3.3	4.4	6.8	9.0	10.2	13.5
14	56 × 49	56 × 47	4.0	5.3	3.8	5.1	7.8	10.4	11.7	15.6
16	56 × 55	56 × 53	4.5	5.9	4.3	5.7	8.8	11.6	13.2	17.4
18	56 × 61	56 × 59	5.0	6.6	4.8	6.4	9.8	13.0	14.7	19.5
20	56 × 68	56 × 66	5.5	7.3	5.3	7.1	10.8	14.4	16.2	21.6
22	56 × 74	56 × 72	6.0	8.0	5.8	7.8	11.8	15.8	17.7	23.7

The Roumanian riveted casing ranges from 16 to 24 inches in diameter, and is made in $\frac{3}{16}$ to $\frac{1}{4}$ inch iron. Some of the casing is made with the vertical seam butting and held by an outside strap riveted on (see Fig. 80).

Casing Shoes.—Whether it is purposed to drive the casing or not it is a good practice to invariably attach a tempered steel shoe to the bottom of each column of casing. These shoes need not be more than 3 to 6 inches deep when heavy driving is not anticipated, and they are a great source of strength to the casing and usefulness to the driller if the casing "hangs" on protruding fragments of rock. Fig. 73 shows the usual type of casing shoe.

When heavy driving is expected a much stronger driving shoe is desirable, and they are either made to screw on to the

casing or to shrink on the pipe direct, after cutting off the threaded portion. Only a very blunt cutting edge should be given or the shoe is likely to become damaged. The steel shoes are always riveted to riveted casing. When the casing itself is rotated and made to perform the drilling, as in some systems of water flush, a circular steel cutter shoe is attached to the casing, as illustrated in Fig. 71.

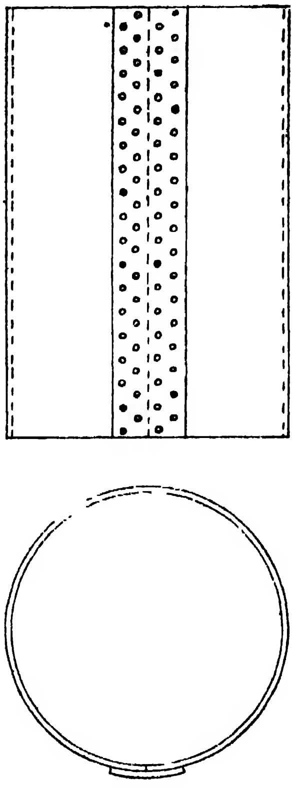


FIG. 80.—FLUSH JOINTED RIVETED CASING.

Casing Elevators or Clamps.—The fall of a string of casing during its insertion in a well is a serious matter and often leads to weeks or months of work for its extraction, if not to the entire loss of the well, consequently considerable ingenuity has been displayed in the design of safety forms of elevators and clamps for manipulating casing. Where ordinary collared screwed casing is used, Scott's or Fisher's patent elevators, illustrated in Fig. 81, are perhaps the best. The elevators simply encircle the casing without gripping it, and the casing is supported during elevation by the collar. Two pairs are necessary, one to attach to a new tube and keep it vertical when being screwed up, as well as to support the weight of the column whilst the other, used beneath the collar on the preceding tube, is being removed. The hinged sides are so arranged that the links, which are curved to avoid the collar, prevent the clamps from opening until they are thrown down horizontally and a safety catch is lifted.

Frequently ordinary wrought-iron clamps are used for raising and lowering casing, especially where the sizes are large, in which case a pair of long links is suspended from the pulley block to pass beneath them. The clamps are made in halves and have provision for two or three heavy bolts furnished with square necks which fit corresponding holes in one side of the clamps. When such screw clamps are used with screwed casing, an elevator for lifting the column is often made by bolting an iron strap to a short

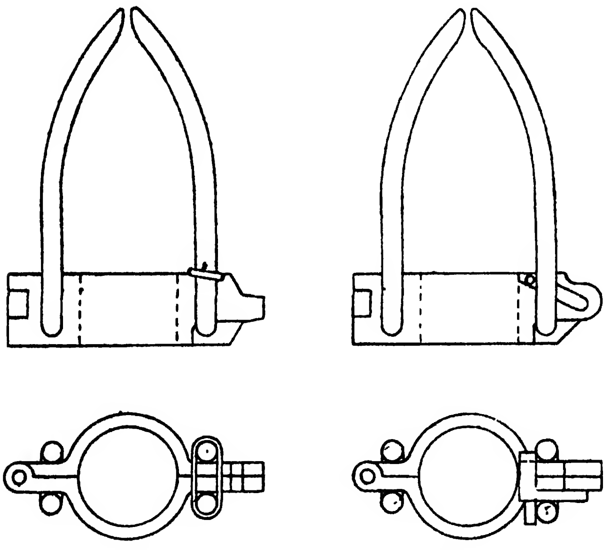


FIG. 81.—CASING ELEVATORS.

screwed length of the tubing, a swivel being provided to allow the rotation of the casing when screwing up. In Canada heavy wooden clamps are often used, held together by 1½ to 2 inch bolts with square threads, washers, and heavy nuts, in which there are sometimes holes for the insertion of hand levers (Fig. 82).

When flush-jointed screwed casing or double-riveted casing is lowered, a special form of clamp is required to support the weight of the column, and some form of wedge block, as illus-

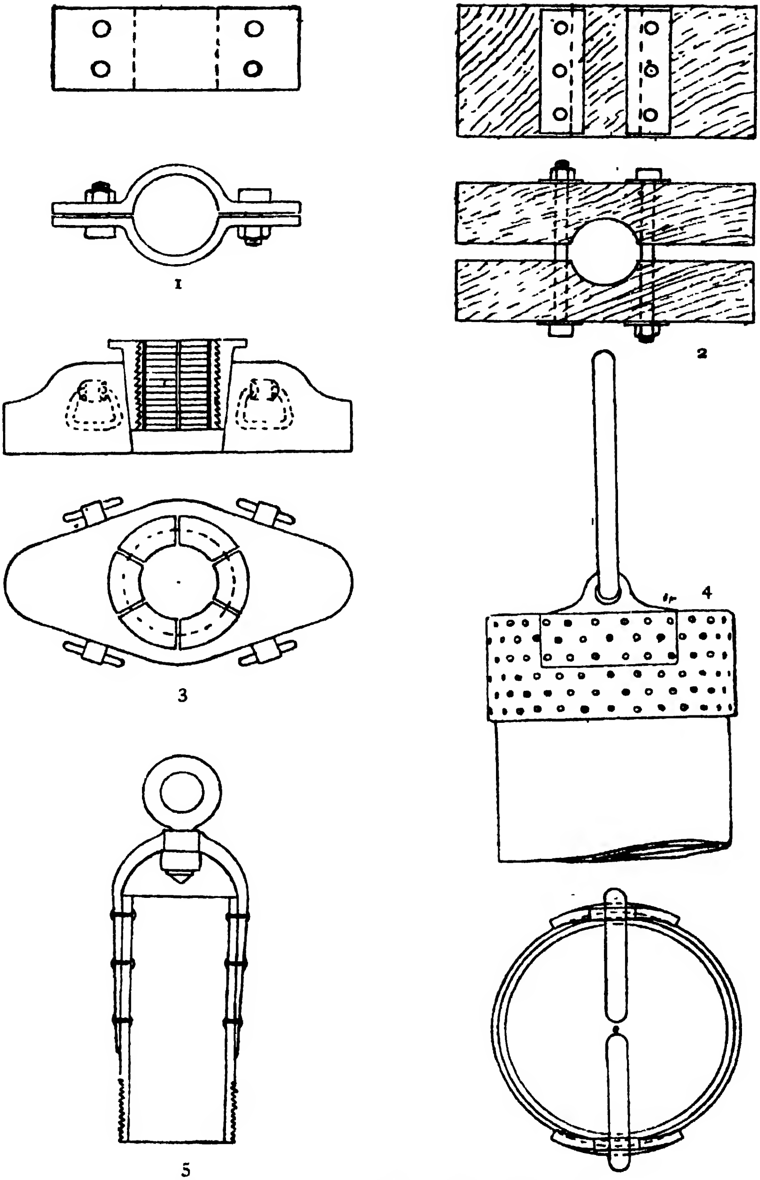


FIG. 82.—CASING CLAMPS AND FITTINGS.

1. Common Iron Casing Clamps.
2. Wooden Casing Clamps as largely used in Canada.
3. Wedge Block used when Jacking up Casing.

4 and 5. Suspension Hooks for lowering Screwed and Riveted Casing.

trated in Fig. 82, is then used. It consists of a heavy forged steel ring in which are internally machined grooves at intervals around, into which can be inserted a number of hardened steel wedge pieces with serrated edges next to the casing. In the wedge block illustrated the wedges are simply placed between a tapered surface of the block and the casing. On lowering the casing the wedge pieces are pressed downwards and inwards and caused to grip the casing, the greater the weight applied the harder being the grip on the casing.

Screwed casing is raised and lowered with the aid of an ordinary screwed connector as already described, the wedge block only being used to support the column when a length is being connected or unscrewed. With double flush-jointed riveted casing a special fork is bolted to the casing through the rivet holes for use when raising or lowering the column.

Cutting and Removing Casing.—When a well has been completed, and several columns of casing have been used in its construction, it is obviously to the proprietor's advantage to recover as much as possible. If no service further than supporting the wall of the bore-hole until the completion of the well has been performed, all the casing, with the exception of the last column, should be jacked up for future use in other wells. Unfortunately, in many cases the casing becomes firmly embedded and cannot be wholly recovered, under which circumstances the tubes can be cut and removed from the point where they do not come into contact with the side of the well, but are protected by the preceding larger column (see Fig. 93). The tubes are cut by lowering a special form of cutter on rods or tubing to the desired position, the rotation of the rods or tubes at the surface causing both the rotation and expansion of the cutters below.

A serviceable type of tube cutter which is largely used in the Russian oil-fields for cutting riveted lap-jointed casing where the work is somewhat severe in having irregular cutting and two thicknesses of metal to cut at the point of lapping,

is as follows: Two guides attached to an exterior, tubular chamber keep the cutter central in the well, and the lower guide, which holds a screwed nut in which a spindle works, is kept from revolving when the rest of the apparatus is rotated by two spring wheels which catch against the vertical lap joint of the casing. When a welded casing is used this guide is kept stationary by springs of a somewhat different design. On the body of the apparatus are three arms, in which are fitted circular or square jaws holding horizontally placed steel roller cutters at the outer edge, the jaws being kept back against the centre spindle by small springs. When the rods at the surface are turned, the whole apparatus revolves with the exception of the lower guide, and at the same time the central tapered cone spindle is drawn downwards by its lower threaded portion working in the nut on the bottom guide. Consequently, as the cutters are rotated, they are slowly forced outward until the tapered length of the spindle has passed and the tube has been entirely severed, after which, by continuing the rotation longer, a recess in the spindle allows the jaws to return to their original position. The exact point when the operation is completed is known by counting the number of revolutions.

A still better tube cutter is that illustrated in Fig. 83, made by Messrs Mather & Platt, Manchester. It is the most perfect instrument of its class that has yet been introduced. By its use it is possible to completely cut the casing, even if it is squeezed into an oval form at the point of cutting.

In the head of the tool is arranged a circular clutch with ratchet teeth, so that if the upper half of the clutch be rotated in one direction by turning round the boring rod, the ratchet teeth slip over each other, and the lower half remains stationary; while if the upper half be rotated in the opposite direction, the ratchet teeth engage, and the lower half is also rotated.

The second portion of the tool consists of a hollow cylinder attached to the lower half of the clutch, in which

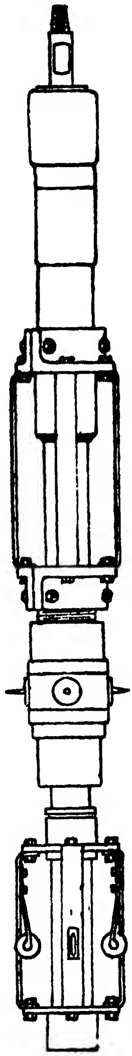


FIG. 83.
MATHER & PLATT'S HYDRAULIC CASING CUTTER.

works a solid rod attached to the upper half. This second portion is provided with external guides to centre it in the tube. Below this comes the cutter proper, consisting of a removable cylindrical body, in which are three or more horizontal cylinders arranged radially. In these cylinders, which are in communication with the pressure cylinder above, there work three or more hollow pistons open at one end, and having circular steel cutting discs mounted in them so as to project beyond the cylindrical body. At the bottom is another set of guides and gripping rollers.

The pressure cylinder having been filled with liquid, which is preferably the same as that in the bore-hole, and the cutter pistons being withdrawn into the cylindrical body, the tool is lowered down to the requisite depth. The boring rods are then rotated in such a direction that the ratchet teeth slip; and the lower part of the tool remaining stationary, the solid rod will be forced down into the liquid in the pressure cylinder, and consequently the cutter pistons will be forced outwards, until the cutting discs bear against the inside of the tube to be cut. On then reversing the direction of rotation, the ratchet teeth engage with each other, and the whole tool is rotated in the tube, the cutters doing their work. When the cut has been completed, the solid rod is forced still further down into the pressure cylinders, and the whole tool can be withdrawn from the bore-hole.

Another form of casing cutter of American design has a

body very similar to other cutters in respect to the cutters, but it is lowered into the well on tubing, and the cutters are pressed outwards by a weighted, tapered spindle, which is suspended by a wire rope inside the tubing. The tapered spindle coming into contact with the inner ends of the cutter holders, forces them outwards when weight is thrown on to the spindle by slackening the rope. Fig. 84 shows this type.

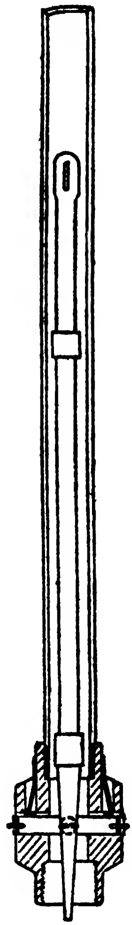


FIG. 84.—SIMPLE CASING CUTTER.

When cutting casing, the column should be kept in a state of tension by jacks, so that separation takes place when the severance is nearly completed, and prevents the breakage of the cutters through the weight of the cut tubes being thrown upon them.

Sometimes it is essential that casing should be removed from a well, but the column cannot be put in motion by jacking or cutting at intervals with a circular cutter; the end is then often achieved by slitting the casing vertically in the part where the exterior pressure is presumed to be holding it. Release is in this way afforded by the partial collapse of the casing, and the column may often be jacked up. There may also be other reasons for slitting the casing, such as admitting sources of oil which have been passed and excluded during drilling, and could not afterwards be opened owing to the fixture of the casing. One form of casing slitter consists of a vertically placed roller cutter mounted on a strong body arranged for lowering on a string of rods or tubes to the desired position in the well. The cutter is either forced outwards against the casing by a strong spring, or a wedge piece is caused to push the cutter outwards

by rotating the rods. The rods are given a vertical movement to a distance equal to the length of the desired slit, until the casing has been entirely cut through. Several parallel slits can be made in the same locality by revolving the rods the desired amount after raising the cutter above the slit.

An American form of casing slitter is shown in Fig. 85.

Another occasional practice is to perforate the casing when an excluded oil source has been passed and it is desired to reopen the source without withdrawing the casing. A form of casing perforator is shown in Fig. 85. The punch pivoted in the centre of the body of the instrument is kept as nearly as possible in a horizontal direction by springs, so that by successively raising and lowering the instrument, holes are punched through the casing, the positions being fixed both horizontally and vertically by marking the position of the rods on which the tool is lowered, at the surface.

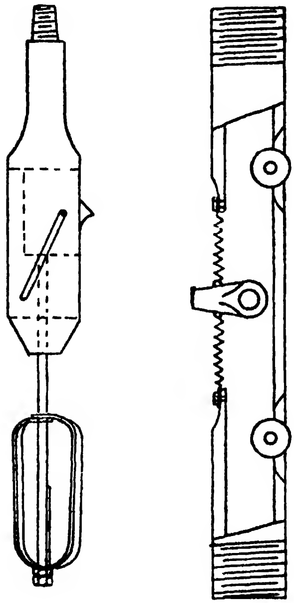


FIG. 85.—CASING SLITTER AND PERFORATOR.

Another form of perforator suitable for small casing consists of an iron body in which is mounted a steel-toothed punch wheel, which can be forced outwards against the casing when lowered in position. The action of raising or lowering the tool causes the protruding arms of the punch wheel to penetrate or perforate the casing in a vertical direction, after which the tool can be released and withdrawn or fixed in another position. Hydraulic punches have been designed for perforating the casing, but they are expensive and somewhat complicated.

Recovering Lost Casing.—When a column of casing has

parted some depth from the surface, either during lowering or in endeavours to jack it up, there are several ways of setting about its recovery. If the column was free at the time of the accident and the threads on the collar or casing stripped, or the casing was broken off at the extremity of the threads (a common occurrence), they may be fished up by lowering a steel threaded die or tap of such a size that new threads can be made and a hold secured. The taps or dies are lowered on heavy tubes or a column of casing which will enable sufficient torsional force to be applied to ensure the dies cutting a thread.

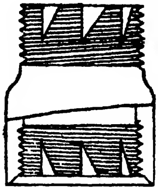


FIG. 86.—TEMPERED DIE AND TAP FOR MAKING THREAD ON LOST CASING.

When riveted lap-jointed casing has been lost, and often in the case of the loss of common screwed casing, a form of casing "spear" or "catcher" is employed for its recovery. The "Bull-dog" casing spear is of simple construction, consisting of two steel segments with serrated edges which slide on taper slides on opposite sides of a steel body. When lowered, the steel segments are pushed upwards along the taper slides into the narrow part, but when the tool is raised the segments remain stationary whilst the thicker part of the tapered body is drawn upwards, thereby forcing the segments outwards. The greater the pull applied to the rods the greater the lateral pressure, but there is obviously no means of releasing the spear should the casing not respond to the pull. A "Bull-dog" spear is shown in Fig. 87.

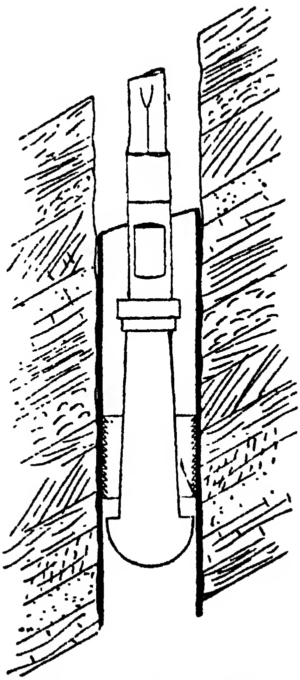


FIG. 87.—"BULL-DOG" CASING SPEAR.

There are many designs of "trip" casing spears which are provided with means of releasing should the casing not respond on the application of power. An excellent casing raiser largely used in Russia, and often designed to deal with casing up to 30 inches in diameter, is shown in Fig. 88. The instrument is of massive construction and great strength, and the sliding segments are brought into contact with or released from the casing by rotating the rods or tubes on which it is lowered. The lower portion of the central spindle is threaded to suit a corresponding internally screwed part of the instrument, so that by screwing up or unscrewing the spindle the links are either forced towards the wider part, or are raised into the reduced width of slides and freed.

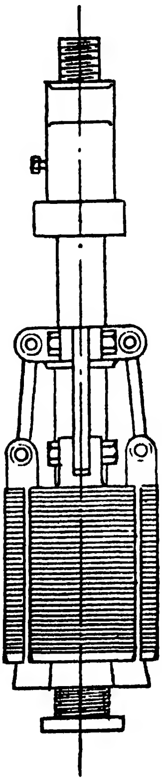


Fig. 88.—Casing Spear or Tube-Catcher as used in Russian Oil-fields.

Many of the American trip spears are designed for use on cable tools so that the jars can be used for freeing the casing.

Repairing Damaged Casing.—Many accidents may occur to casing through causes beyond any one's control during the drilling of wells, and special tools for dealing with casing troubles are always stocked by contractors and large oil-well operators, although they are rarely supplied with prospecting plants. The most frequent damage sustained by casing is bulging, generally as a result of excessive gas or water pressure behind the casing, or by a landslide. Sometimes the damage is slight but sufficient to prevent the passage of the drilling tools, whilst at other times the collapse is complete

and almost closes the hole. If the damage is near the surface the tubes may be withdrawn and the faulty tube replaced, but this is not always practicable, and is often attended with risk in a deep well. The usual procedure is to lower a "swedge" or "drift" and cause it to pass the damaged spot by the direct weight of the tool and the rods or tubes on which it is lowered, or in the case of cable drilling by the use of the jars. If the bulge is considerable a small drift is used first, followed by larger and larger until the original size has been reached. The swedges or drifts are conically shaped steel bodies, sometimes fluted to allow the passage of water or mud past the tool. Some drifts are built up with discs increasing in sizes towards the centre which are strung on a square spindle to which they are firmly held by a nut, when the number of discs gives the desired diameter.

A very useful drift is used in Baku. Three steel rollers run upon spindles mounted in eccentric form, so that by turning the spindles and fixing them by a set-screw in a different position, the rollers can be made to extend further or be drawn towards the body of the tool, thus increasing its range of action. The apparatus is lowered on heavy fishing rods or tubes, and caused to pass up and down through the bulged piece of casing until it passes freely when turned completely round.

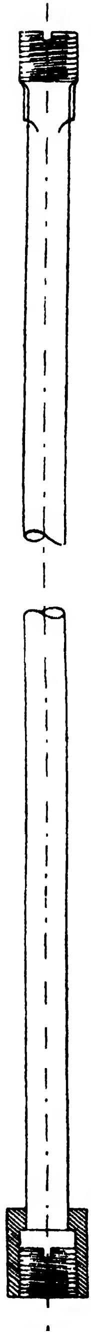


FIG. 89.—FISHING RODS FOR HEAVY WORK.

CHAPTER VII.

Exclusion of Water from Oil Wells.

Injurious Effect of Water in Petroleum Fields—Exclusion of Water by Casing—Packers—Cementing Process of Excluding Water.

Injurious Effect of Water in Petroleum Fields. — There are few oil-fields where water-bearing beds are not found dispersed amidst the oil-bearing strata, or to which water does not find admission, in some quantity, when the beds have been disturbed by numerous bore-holes and by the abstraction of great volumes of petroleum. Time after time oil-fields of great promise have been abandoned after the expenditure of fortunes on fruitless attempts to check the apparently almost limitless volumes of water which entered the wells and displaced the petroleum as soon as its extraction was commenced.

The location of water-bearing strata can usually only be ascertained by direct experiment, and its underground movement is influenced by numerous fault planes which frequently traverse oil strata when they have been folded and tilted into inclined positions. As the great petroleum supplies of the world are largely confined to porous sands which lie intercalated between beds of clay or shales, it follows that any sandy layer not impregnated with petroleum will most likely be charged with water. In practice such proves to be usually the case, and unless fairly thick, impervious seams of clay separate the water and oil-bearing sands, much difficulty will be found in its exclusion.

In the United States there are examples in the flooding of Humble Pool, Texas, and of the reluctant abandonment of Batson Prairie, Texas, through salt water when the early

wells gave so much promise, and from which a production of 1,450,000 tons of oil was obtained in the year 1904; and in Russia there is the recent abandonment of Berekei where pioneer wells flowed for months at the rate of 80 tons of oil daily, and led to considerable activity in the district, but where nearly all wells were subsequently flooded by flowing streams of hot sulphurous water after the oil was struck. Zabrat, a district of the Baku oil-fields, although proved by isolated flowing wells to contain great quantities of petroleum, has been practically abandoned owing to the impossibility of excluding the water which permeates many of the intermediate strata and floods the wells as soon as they are bailed.

In Texas and Louisiana thick beds of water sand have to be passed before penetrating the oil series, and unless the water is totally excluded the wells are valueless. Many of the original wells in parts of the Baku oil-fields flowed water at a shallow depth, whilst in the western part of the Grosny field of Russia a large proportion of the wells penetrate a stratum which flows hot sulphurous water in immense volumes, although good supplies of petroleum are found beneath when the water is excluded. Some of the Californian oil-fields have been almost ruined by admitted water after the reduction of gas pressure.

When an oil source is struck beneath a water-bearing stratum a moderate production of oil may be maintained for a while, if the water is only imperfectly excluded by the casing, on account of the pressure of the oil, but as soon as the gas pressure diminishes, and the natural level of oil falls below the hydrostatic head of the water, the latter enters the well and mingles with the oil. For a while an emulsified mixture of oil and water may be raised, but as the water increases in volume and cuts a passage behind the casing, the oil is steadily replaced, and an increasing volume of water at length totally excludes the oil from the well, although the gas may continue to escape. As a rule the entrance of water has then proceeded too long to allow any effectual measures for

its exclusion, such as might have been undertaken when the well was first completed.

The loss of a single well through negligence is not a matter of serious concern to any one but the proprietor, but unfortunately the evil consequence of such work is not confined to the isolated example, as, with the partial exhaustion of the oil, water flows into the oil stratum, mingles readily with the oil, and on account of its less viscous character readily finds a channel to points where oil is being extracted. More cautious operators who have expended time and money in excluding water find it entering their wells, and subsequently they are compelled to abandon them on the total displacement of oil by water.

In many fields certain legislation has been introduced to enforce operators to adopt measures of safety involving the welfare of the whole district, but this can naturally only be of a limited description as subterranean movements of water are irregular and affected by local structural features of which no one is acquainted. Measures of safety, too, may be so imperfectly executed that they are valueless, yet it is difficult to bring home any charge of negligence.

Exclusion of Water by Casing.—Where the wells are of a moderate diameter, and welded screwed casing is employed for lining, water can generally be totally excluded from oil wells by driving the tubes into an impervious stratum above the oil bed. In unexplored territory, where little or nothing is known of the character of the beds, or of the depth at which oil beds will be struck, it is good policy to proceed as far ahead of the casing as possible with a reduced size of drill if water has been passed, so that if an oil source is discovered the casing can be driven or "set" in the most suitable stratum above the oil bed. Should no impervious bed exist near the oil-bearing stratum one of the methods described hereafter must be employed for excluding the water, but by driving the casing shoe firmly into a clay or shale a

watertight joint can usually be effected when the casing is good. The exclusion of water in this way often leads to a flow between the casings, and it is no uncommon sight in some oil-fields to observe oil flowing from the inner casing

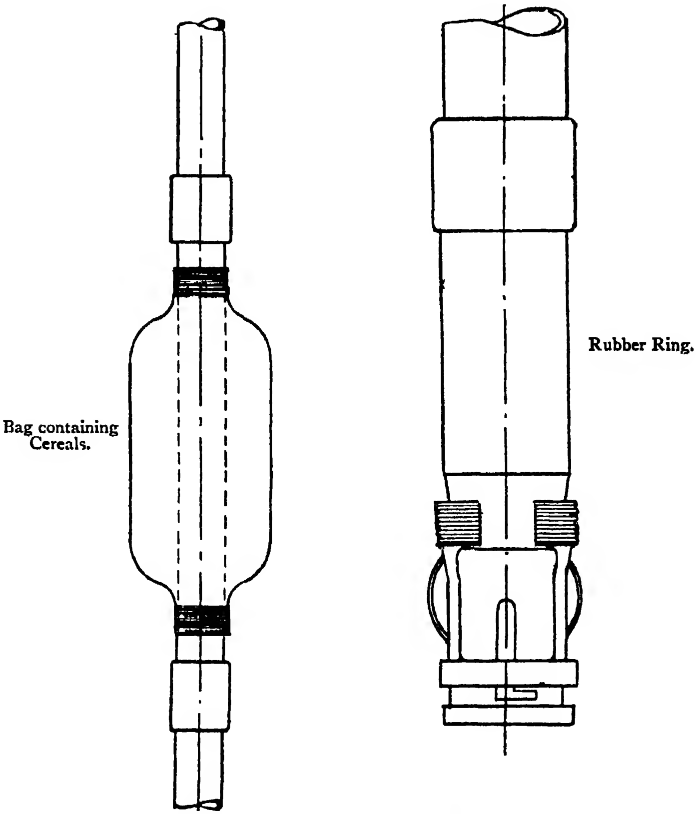


FIG. 90.—TWO FORMS OF PACKERS.

1. Bag containing Cereals.
2. Rubber Packer that can be set in any position and Rubber expanded by weight of Casing.

and water flowing from the annular space between the casings.

Packers.—Water sources can often be effectively isolated by the use of packers, more especially where good screwed

casing is used. In the early days packers were made by binding to the casing at the desired spot bags of meal or other cereals, and then lowering the column into the well. When the meal bags are sunk to a position below the water strata where fairly compact beds occur, the contents gradually swell by absorption of water, and form a watertight joint between the sides of the casing and the well. A somewhat similar use of hemp is sometimes made by binding strands around the casing at a point where the upper loose ends will just pass beneath the shoe of the preceding column when it is lowered. On drawing the column upwards after lowering, the ends of the strands are bent back, and push the whole hemp into a bulky mass, which presses against the sides of the well as the casing is raised. Both these processes are of a temporary nature only, and it is usual to use specially designed packers which ensure absolute and permanent exclusion of water if properly inserted in suitable strata.

Many packers depend upon the resiliency of rubber to produce a watertight connection, the expansion of a rubber cylinder being usually performed by direct pressure, or by a tapered cone. Fig. 91 shows a common form of packer, which can be lowered on the pump tubes. The rubber is extended by the pressure due to the weight of pump rods, its position being fixed by attachment to a perforated pipe extending below the packer, and resting on the well base. The oil and gas enter the perforated tubing below the packer, and they either flow unassisted to the surface or are pumped, whilst the water finds its level in the well above the packer. With this type of packer, as in all others, the position must be carefully selected where there is a hard stratum, otherwise the surrounding material will crumble away behind the rubber, and the packer will fail in its object of excluding the upper water.

Fig. 92 shows one form of packer which can be lowered direct on a column of pump tubing to any desired position

below the water-bearing stratum, and "set" by rotating the tubing to the left. The expanding wings prevent the lower part of the packer from revolving, and the rotation of the tubes in a left direction causes a tapered cone to descend

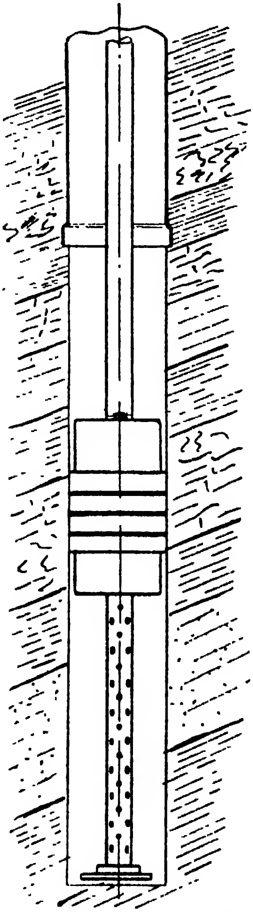


FIG. 91.—PACKER THAT CAN BE SET BY WEIGHT OF TUBING.

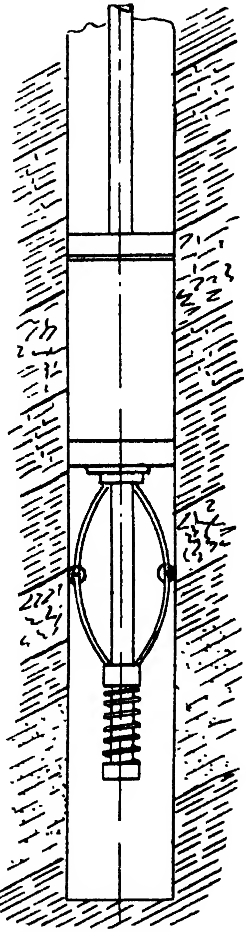
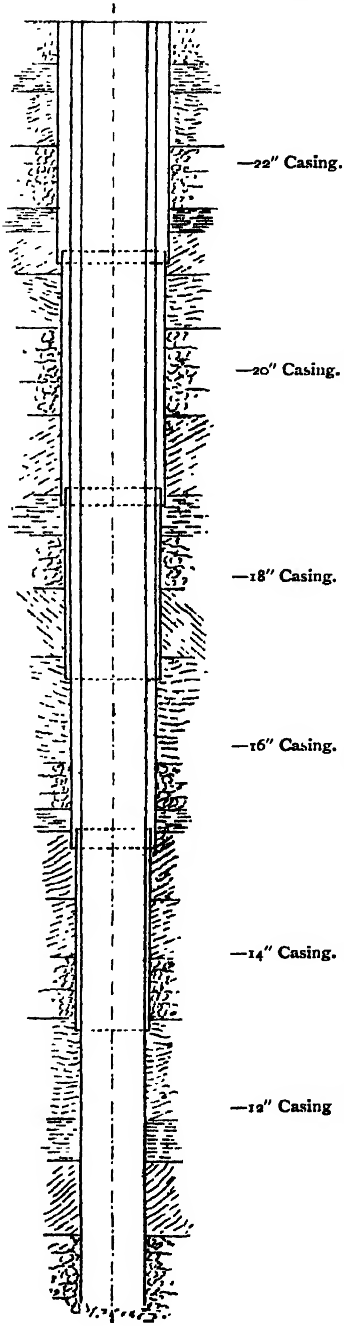


FIG. 92.—PACKER THAT CAN BE SET BY ROTATION OF TUBING.

and extend the rubber ring. The release of such a packer is effected by rotating the tubing to the right.

Packers which come into operation as a consequence of the weight of casing are sometimes attached to strings of



casing at such points that overhead water or caving ground is entirely excluded. Sometimes two such packers are used separated by a few lengths of casing when it is desirable to exclude either a flow of water or a strip of caving ground, whilst prospecting deeper. Such packers are brought into play by the release of a catch internally, which causes a powerful spring to force upwards several wedge pieces encircling a conical external part of the body, so that the greater the weight of casing above, the more firmly the packer is held in position, and the more the rubber fixed above is expanded. It is possible to unscrew and remove the casing above the packer if considered expedient, and it is desired to leave packers so set when the well is put to pumping.

Cementing Processes of Excluding Water. — In some oil-fields where there is a noticeable absence of compact strata, or where riveted casing has to be employed on account of the large dimensions of the wells, water is often shut off by a process of cementation. Fig. 93 illustrates a section of a large well

where each successive column has been cut and removed from a point a little above the shoe of the preceding one, leaving an annular space of varying size to the surface. If this space is filled up with cement, not only is the well vastly strengthened, but water is prevented from passing down behind the casings as well as through faulty rivet holes and defective seams in the casing itself. Such a cementation is a long and costly operation only justified by extreme necessity, as the inner casing has to be filled with earthy matter before the cementation commences to prevent a collapse of the casing and the entrance of cement into the well, and a long interval must elapse before the inserted material can be cleared out whilst the cement is setting in the annular space. It is advisable that each shoe should be carried into solid ground, otherwise large quantities of cement are often absorbed by loose, partially exhausted oil sands, and even carried underground and bailed from oil wells in the vicinity.

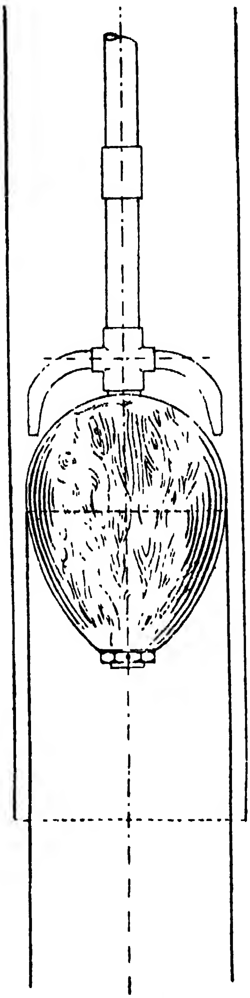


Fig. 94.—Apparatus for Cementing Shoe of each String of Casing.

Before commencing a cementation all oil should be removed by bailing and washing between the casings by pumping water down, as a proportion of oil adversely affects the setting of the cement. When there is a high column of liquid in the well the filling can only be performed slowly, or air locks will be formed where cement will subsequently enter and cause trouble to drill through on cleaning

the plug. The material for a plug must be carefully chosen, or it may prove as difficult to remove as drilling a new hole. Some sands are suitable, but others set very solid, and it is preferable to mix as much clay as possible with the sand to facilitate its abstraction.

A fluid cement with admixture of clean sand of the consistency of cream is stirred up in wooden or iron tubs at the surface, and this is poured through tubes which extend in diminishing size to the lowest point. The upper portion may be 2-inch, followed in succession by portions of $1\frac{1}{2}$, 1, and $\frac{3}{4}$ inch, whilst a large funnel directs the flow into the tubing at the surface. The descent of a thoroughly mixed solution is thus assured to near its resting place, and no great separation of sand and cement can take place if the tubes are only raised gradually as the cement is inserted. To ensure the proper settlement of the cement the process is conducted in stages, so that the complete operation to the surface occupies several days. It is an advantage to use an almost pure solution of cement at first and gradually add increasing quantities of clean, sharp sand as the surface is approached.

Sometimes each column of casing is separately cemented as the well proceeds, in which case it is customary to underream below each shoe for several feet, and when the succeeding column has reached its final position and has been cut out, to lower the apparatus shown in Fig. 94 on 2-inch tubes, and fill the annular space with cement.

It will be understood that when such a complete cementation fails in its object, little can be done to remedy any defective setting or other cause of failure. In such extreme cases the lower part of the well is sometimes filled with cement and left to set, with the uncertain prospect that sufficient cement may enter the ground near the shoe and collect behind the casing to form a solid block. Sometimes the lower part of the casing is perforated with the instrument described on p. 256 before the cement is inserted, thus opening other channels for the cement to pass around the casing.

CHAPTER VIII.

THE EXTRACTION OF PETROLEUM AND NATURAL GAS.

The Extraction of Petroleum from Pits—Natural Flowing Oil and Gas Wells—Methods of inducing Artificial Flow of Oil Wells—Pumping—Bailing—Air-lift Process—Compressed Air Systems—Raising Petroleum by Absorptive Endless Belt—Cleaning Oil Wells.

Extraction of Petroleum from Pits.—Hundreds of years before the knowledge that petroleum in large quantities could be obtained by drilling wells, oil was raised from shallow pits sunk amidst seepages and along outcrops of oil-bearing strata, and the petroleum which by degrees oozed from the containing bed and accumulated in the pits was either skimmed from the surface of water upon which it collected, or was raised in some description of vessel by means of a windlass. This rough method is still practised by peasants and natives in many parts of the world, but particularly in Roumania, where the hand-dug pits have for years been a considerable source of revenue to producers, and have in some districts been the main, if not the sole, source of supply.

In Roumania the hand-dug pits are often 600 feet deep and yield as much as 10 tons of oil daily, its extraction being accomplished by the aid of a mule or pony harnessed to a pole fixed to a wooden drum about 4 feet in diameter around which is coiled the winding rope. The barrel is permitted to rapidly descend by gravity when the drum is disconnected from the shaft, and as soon as the attendant has ascertained that the barrel is filled, the drum is attached by a pin to the shaft and the horse driven round; the horses are generally blindfolded to prevent them becoming giddy.

Often bullock skins are used for the extraction of oil from pits, in the same way that water is drawn from wells to-day in the East.

In parts of the Caucasus supplies of petroleum are obtained for local consumption from pits by means of a bucket attached to a rope wound round a spindle from which there extends four projections at right angles, its withdrawal being performed by a peasant who uses both his feet and arms on the projections for rotating the winch. Another common method of raising oil from shallow pits is by means of a long pole pivoted at its centre on top of a vertical support. One end of the pole is vertically above the mouth of the pit when horizontal, and from that end is slung with a rope the bucket or vessel for containing the oil. On the opposite end of the pole is a weight to nearly balance the bucket, and a cord which the operator pulls down when the bucket has filled, and so raises the oil to the surface.

Natural Flowing Oil and Gas Wells.—In most oil-fields of the world the penetration of a virgin oil source at a moderate depth often leads either to the fierce expulsion of oil by gas or a steady flow on account of the reduced weight of the column of liquid through the evolution of gaseous hydrocarbons which are dissolved in the petroleum. So long as the oil source yields petroleum in sufficient quantities to replace that discharged, and so long as the gaseous products aerate the column to the requisite degree, the well will flow unassisted, but if the petroleum does not issue from its source in sufficient quantities to replace that ejected, or the volume of dissolved gaseous hydrocarbons is insufficient to carry the oil to the surface, the discharge ceases. The flow may cease entirely, but usually the oil is expelled intermittently, the period between successive discharges depending upon the volumes of gas and inflow of petroleum.

An oil well generally exhibits a disposition to flow by a free evolution of gas and often a high and fluctuating level

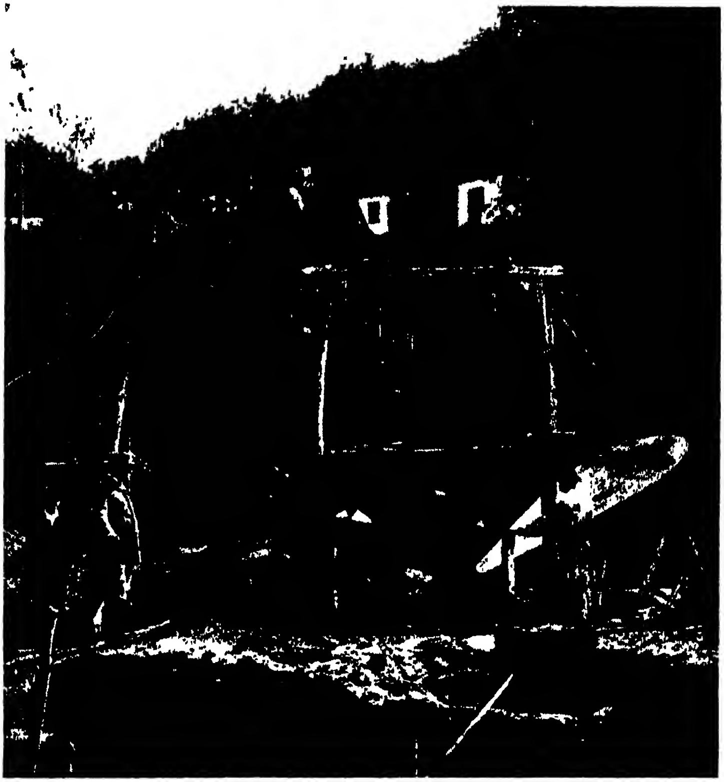


FIG. 95.—SINKING SHAFTS BY HAND IN BUSHTENARI OIL-FIELD OF ROUMANIA

of liquid. The level of oil in such wells not infrequently fluctuates many hundred feet in the course of a few minutes, a big drop being accompanied by the issue of a large volume of released gas.

Oil frequently flows incessantly or intermittently for several days, weeks, or even months when a prolific source has been penetrated, and in most fields the wells which show a tendency to flow when nearing completion are fitted with a surface attachment having several lateral outlets through which the oil can be led away to reservoirs. The "casing head," as it is technically called, is screwed on to the casing and has a recessed top into which an iron cap may be placed and fixed in position by set-screws, the oil being thus deflected into the side openings, through connecting pipes which are often controlled by valves.

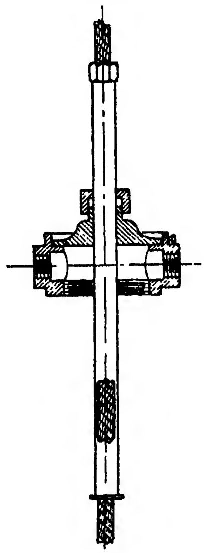


FIG. 97.—OIL SAVER.
For continuing Drilling when Oil flows.

When drilling with a manilla or wire cable through an oil stratum which is sufficiently prolific to cause the oil to periodically flow, an externally turned and polished tube called an "oil saver" is attached to the cable near the surface of the well, and this works in a gland which replaces the cap of the casing head, consequently should the well flow whilst drilling is in progress the oil passes away through the side outlets without much loss or hindrance to the work. During the operation of cleaning a well with a bailer or sand pump, wells are very liable to spout, and a flat iron cap, through which a small hole is left for the wire bailing rope, is attached to the casing head. On the completion of a flowing well the casing head is left in position with the outlets open, 2-inch or larger pipes leading the product away to the storage tanks.

When powerful discharges of oil are expected on penetrating the oil stratum, it is customary to attach to the casing strong valves, which permit the outflow to be adjusted after attachment, but where the intention is to thus control the outflow, the valves and casing must be firmly anchored to the earth by strong bolts, otherwise the valves and upper lengths of casing may be blown away.

In the Russian fields, where the wells have finished diameters of from 12 to 20 inches, and much sand accompanies the petroleum, controlling devices have never proved a success. In the Baku fields many attempts were made to control the output of wells by means of heavy gate valves, but with pressures of from 100 to 500 lbs. per square inch in riveted casings of 12 to 20 inches diameter and great volumes of sand accompanying the oil, all devices failed. Such a powerful sand blast action was set up that cast-iron or steel surface valves were cut to pieces in a short time when opened, whilst if the flow was entirely checked the large casings generally burst, leading to permanent injury of the wells.

For many years it has been the practice in Baku and Grosny to place a massive steel or chilled cast-iron shield some 15 to 20 feet above the mouth of the well; the discharged mixture of oil, sand, and stones being thereby prevented from rising hundreds of feet into the air and becoming dissipated by the winds. Heavy cross timbers, to which the 12-inch blocks are bolted, are placed in the derrick when a flowing well is expected, and the timbers are so arranged that the block can be drawn over the mouth of the well by ropes from a distance when a flow commences or appears imminent. So destructive is the fiercely discharged mixture of sand, oil, and gas, that the massive Russian derricks are often totally destroyed, and evén the chilled iron blocks have been perforated one after another in succession by a particularly violent gusher. The unexpected appearance of a powerful gusher generally leads to the loss of great quantities of oil through the absence of provision of

a "fountain shield," the oil being ejected through the summit of the derrick to a height of 100 to 300 feet with such impetuosity and with so much gas that the well cannot be closely approached. In such cases a side timber structure is often built to the derrick at a height of about 20 feet, and massive fountain shields are pushed over the mouth of the well from the side. The stream of oil is directed along channels, kept open in the accumulation of ejected sand by gangs of labourers, to a depression where the pumps can deliver it to the storages.

Wells sunk chiefly for gas, as in parts of Pennsylvania, West Virginia, Canada, and Surakhany near Baku, are "capped" as soon as possible after penetrating the gas stratum, and the outlet led direct into the gas mains if reasonably free from sand and moisture. Gas wells frequently yield 10,000,000 cubic feet of gas daily, and have an open pressure of 10 to 20 lbs. per square inch, whilst the closed pressure frequently reaches 500 lbs. or sometimes 700 lbs. per square inch. The rapid expansion of escaping gas with which some moisture is usually associated causes a considerable reduction of temperature at the mouth of the wells, and either a gas jet or a large fire has often to be made over the well to prevent the freezing up of the pipes. When sand accompanies the gas the outlet pipe is led into large receivers with numerous baffle plates where the diminished velocity causes the deposition of the sand before the gas passes into the mains.

In Russia, Borneo, and elsewhere, the capping of flowing wells has frequently led to the total exclusion of the oil, apparently through the plugging of the channels through which the oil had flowed, and as a result of the high pressure of gas which accumulated in the well. To avoid such an eventuality in localities where the danger is known to exist, it is advisable to only partially check the flow when the well is capped, thus keeping open the channels through which the oil is feeding the well.

Flowing wells occasionally take fire as a result of accident

or negligence, and when the flow is very powerful and many hundreds and even thousands tons of oil are being daily consumed the extinction of a conflagration is not a simple matter. The most effective means of extinguishing a burning gusher which cannot be capped is to suddenly inject into the flame a great volume of some non-combustible gas which prevents access of air to the flame. For this purpose steam is an effective agent, and if the steam from a number of pipes, each coupled to a boiler under high pressure, is suddenly directed upon the flame it is often extinguished. Carbon dioxide gas and other chemicals have likewise been employed for the same purpose with varying success. In some cases the well casing is approached by tunnelling beneath the ground, and the casing squeezed flat with hydraulic jacks.

Methods of Inducing Artificial Flow of Oil Wells.— After a well has flowed naturally for awhile, the discharges become less and less frequent until they cease altogether, but often long before the period of total inactivity is reached, a column of 2 to 3 inch tubing is lowered into the well, and the space between the tubing and well casing sealed, so that the diminishing quantities of gas are thereby forced to escape through the reduced sized piping. If there is still a fair evolution of gas, the oil may continue to flow unaided for a further time, until the reduced output makes it necessary to use mechanical means of raising the oil. Sometimes a packer is attached to the tubing near the bottom of the well, the gas being thereby compelled to find a direct outlet through the small tubes without collecting under pressure in the well above the oil. Packers are fully described under water exclusion, p. 264.

Most oil wells where there is a high level of liquid or a fair quantity of gas can be induced to flow by closing the outlet of gas for a while, when the liquid becomes supercharged with gas and will be ejected with the gas when relief is afforded.

Such a well gives from 10,000 to 14 000 tons of oil and often from 10,000 to 20,000 tons of sand daily.

The side structure to the derrick is for the erection of a fountain shield to push over the mouth of well.

FIG. 98.
GREAT GUSHER IN BAKU OIL-FIELDS OF RUSSIA.

Sometimes the period of flow can be economically increased by intermittently admitting a small quantity of compressed air to the bottom of the well through small tubes, the aeration being sufficient to cause the oil to flow. The most efficient period between successive admissions of air must be ascertained by direct experiment in each separate case.

Pumping.—The method of extracting petroleum from an oil well is decided by circumstances, which are to some extent dependent upon the following conditions :—

(1.) Amount of gas evolved.
(2.) Depth of well and sometimes diameter.
(3.) Level of liquid.
(4.) Amount of sand suspended in the oil.
(5.) Productivity of petroleum sources.

By far the most general and the cheapest method of extracting petroleum from oil wells is by pumping, but this is not always possible on account of sand accompanying the oil in great quantities.

The common oil-well pump is a cylindrical steel chamber from 4 to 7 feet long, screwed at the upper and lower ends for the attachment of the rising main and suction valve respectively, in which a plunger or bucket, fitted with an internal valve, moves. The hollow plunger is either externally recessed for a wrapping of hemp, or made to take several cup leathers, whilst the interior has a machined face at the top on which a ball valve between guides finds a seating. The lower or suction valve consists of a fitting with a gun-metal or steel ball valve and seating, the body of which is suitably packed with hemp or cup leathers to tightly fit the pump barrel, and rest upon a protrusion on the suction attachment. The pump barrel is lowered on 2 to 3 inch tubing to the bottom of the well, the pump plunger being lowered into the barrel by "sucker" or pump rods. The

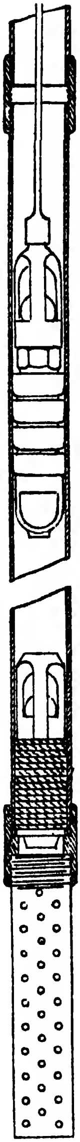


FIG. 99.
COMMON OIL-WELL PUMP.

lower end of the plunger is often screwed to correspond with a similarly screwed portion of the suction valve, so that by lowering the plunger carefully upon the suction valve and rotating the sucker rods a few times, the lower valve can be attached to the plunger and withdrawn from the well with the plunger for examination without removing the tubing to which the pump barrel is connected.

There are many kinds of packing and cup leathers used for pump plungers, the most useful one for a particular district depending chiefly upon the quantity of sand or clay present with the oil. Californian producers favour a plain metal plunger without packing, whilst others prefer various qualities of plaited hemp wound round a recessed plunger. Even with cup leathers there are several kinds, each of which has its advantages for certain work. The well-known "bow spring" is one which gives general satisfaction where there is always a certain proportion of fine, gritty matter with the oil, but for general work good quality plain leather cups are difficult to surpass for wear. Some working plungers have provision for taking up the wear of the packing by expansion methods, either automatically or by manipulation from the surface. The "Landas" valve and plunger is packed with rope, which is always kept tightly expanded by a coil spring, which presses upon a sliding collar in contact with the upper end of the rope packing. Some forms of rope packing plungers can be expanded by lowering on to the lower valve, and rotating the sucker rods at the surface, whilst the "Lewis" plunger valve has rubber rings which can be expanded in the same way.

In some oil-fields, where there is a high level of liquid maintained after the flowing period has ceased, and there is no formation of sand plugs, the oil is raised by means of a heavy iron piston or "swab," slightly less in diameter than the casing of the well, fitted with a valve opening upwards on its upper surface. The plunger is lowered on a steel wire rope to the bottom of the well from a winding drum, and then raised at a velocity of from 1,000 to 1,500 feet a minute, the oil above the plunger being thereby lifted, and flowing over the mouth of the casing. Such a process is only possible when good round screwed casing has been used to line the well, as if the diameter of the plunger is reduced much below that of the casing the slip is excessive.

Pump Tubes.—The pump tubing on which the pumps are lowered is specially made for the purpose, ordinary piping not being satisfactory. It is usually slightly heavier than standard piping, the sockets are longer, and the screwing must be absolutely true to ensure a straight column when coupled up. The joints must very nearly butt, and the inside edges must be slightly chamfered to remove any burrs which would damage the packing or cup leathers during insertion. The tubing must also be quite round and free from rough edges or seams internally, and should be all tested prior to use by the insertion of a plug slightly less in diameter than the tubing.

Sucker Rods or Pump Rods.—Sucker or pump rods partake of several forms, their choice being largely dictated by cost in the locality in which they are used; ½ to ¾ inch diameter tubing is often used, but where the wells are deep specially long sockets should be attached. A very popular practice is to employ round or octagonal wooden (ash) poles with screwed straps riveted to the ends as in ash drilling poles, and their lightness and reduced weight when submerged in liquid are certainly contributory advantages.

Under normal circumstances the author is disposed to favour the use of solid iron and steel sucker rods, especially

when the size of pump tubing does not exceed 2½ inches diameter. The solid rods are from $\frac{9}{16}$ to $\frac{7}{8}$ inch in diameter, and have screwed ends and collars for their attachment and suspension from wrenches or elevators. Spare screwed ends should be kept in stock for welding to the rods if an end becomes damaged.

For lowering tube sucker rods a small hinged clamp with suspension slings is used, and the joints are screwed up with pipe wrenches, but with wooden or iron sucker rods a convenient elevator, shown in Fig. 100, is used. When held horizontally the wrench part passes freely below the collar on the rod, but on attaining a vertical position the extending limb prevents the rod from slipping out.

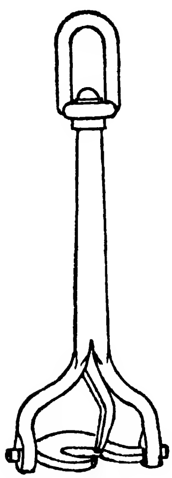


Fig. 100.—Sucker Rod Elevator.

When an oil well has been completed and set to pumping, it is usual to leave the derrick and bull wheel for withdrawing the sucker rods when the pump leathers or packing need renewing. With wells of 1,000 to 2,000 feet in depth some six men are needed to manipulate the rods, and they raise the rods by turning the bull wheel to which a light wire line has been attached after passage over a small pulley in the summit of the derrick. Where no derrick is left, and in some cases where the derricks do remain, the rods are lifted by horse-power in conjunction with a portable form of shear legs which can speedily be erected and conveyed about the field.

Occasionally steel wire rope is used for working the plunger, in which case a take-up screw must be placed at the surface so that the stroke can be accurately adjusted to compensate for the spring of the rope when the pump is put in motion. When a wire rope is used sufficient rods must be attached to the plunger to ensure its free return after each upward stroke.

Surface Fixtures for Pumping.—When trial pumping an oil well the walking beam of the drilling rig is generally used for transmitting the motion to the pump rods. A casing head is attached to the top length of casing, and from the side outlets are led two pipes to conduct the gas and, if the well flows, the oil also to the desired positions. The gas can be led away direct to the boilers to be burnt as fuel, or may be conducted to reservoirs from which gas engines derive their power.

The rising main tubes are continued to a height of about 2 feet above, when a tee is introduced into which the oil outlet pipe is led which connects with the storage. Above the tee is attached a brass stuffing box in which works a polished steel rod screwed to the sucker rods, and which can be connected to the walking beam at any desired position by a "grip adjuster." This method is sometimes retained for permanent pumping, but more often the walking beam is replaced by some smaller and more convenient form of motion transmitter, especially as wells are generally pumped in groups by means of "jerker" lines which transmit a horizontal motion.

Where wells are widely separated or individual or isolated wells have to be pumped, the walking beam system is to be recommended, as the crank-shaft takes its drive direct from an electric motor, gas, oil, or steam engine, or other motive power which may be employed. In the hilly districts of West Virginia electricity is largely used in this way by the South Pennsylvanian Oil Company for pumping widely separated wells where the production from individual wells often does not exceed half a barrel of oil daily.

The bell-crank lever is the almost universal method of pumping when a horizontal tensile movement has to be transformed into a vertical reciprocating motion. Where timber is inexpensive and ironwork is dear on account of freight or duty a wooden crank may be used, but a lighter and more convenient form of pumping "jack" is shown in Fig. 101. The timber crank can be made by any

carpenter, and can be strengthened by the addition of a few wrought-iron plates. A wrought-iron stirrup connects the "jerker" line to the crank, and a simple connecting joint couples the oscillation beam to the crank. A considerable amount of power can be saved by partially balancing the weight of the sucker rods by extending the oscillation beam on the side removed from the well and suspending weights near its extremity.

Metal pumping jacks are made in combined wrought and malleable iron, and sometimes for lightness and simplicity in

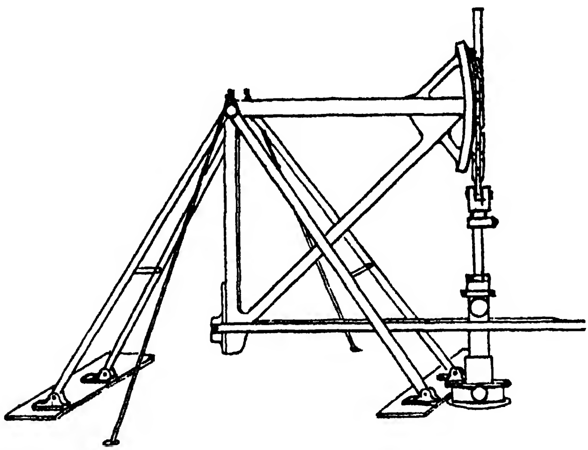


FIG. 101.—SIMPLEX PUMPING FRAME.

wrought-iron tubing. The "Simplex" type made by the Oil Well Supply Company is quite suitable for wells of medium pumping capacity, and has given satisfaction where installed under the author's direction. The heavy size of pumping jack only weighs about 500 lbs. and costs about $20, and it has the special advantage over many other types of transmitting a direct pull to the pump rods, and avoiding the lateral strains which are thrown on the polished rod and gland in ordinary methods.

Action of Pump.—Rarely do cylinder pumps in oil wells yield a pulsating flow of liquid corresponding with the stroke

of the plunger, but at irregular intervals oil is discharged for several minutes in one continual full bore stream with some force, during which period the flow is in no way connected with the action of the pump, but continues even if the pumping be stopped. When there is but little gas, each stroke of the pump causes a discharge of oil, but whenever there is much gas present, the above-described intermittent action results. At times the gas disengaging itself from the oil prevents the ball valve of the plunger from resting on its seating at each upward motion of the plunger, with the result that the discharges of oil only take place when the column has been sufficiently reduced in weight by the gas to flow. The agitation of the oil by the pump rods conduces to this intermittent action by assisting the liberation of gas.

Where wells are pumped dry, and petroleum only slowly exudes into the well, a great saving can often be effected without any loss of production by pumping the wells intermittently and allowing the liquid to accumulate.

Transmission of Power for Pumping.—Where it is necessary to instal at each well a complete pumping arrangement, including motor, the extraction of oil becomes costly; indeed, the profitable exploitation of some oil-fields is entirely due to the cheapness of multiple pumping. The size and strength of a pumping unit is decided by (1) the nature of the ground, (2) the distance of the wells apart, (3) the size of the pumps, (4) whether the wells are pumped continuously or intermittently. If the ground is fairly level and open, and the wells are not further removed than 600 to 700 feet from each other, units of forty to fifty can be pumped with economy by "jerker" lines, but many oil producers prefer pumping units of twelve to twenty-five wells on account of the fewer number of wells that become unproductive if a breakdown occurs.

In all cases a central station is needed, where the power is either generated and transmitted to the wells or transformed into suitable motions. The power itself may be electricity, steam, or internal combustion engines, but in all

cases it is transmitted by gearing or belting to a frame that actuates the wells through the medium of tension rods. Power is only needed for lifting the bucket when pumping, as the weight of the rods carries the plunger back, consequently all the power applied to the wells is tensional. This fact enables considerable power to be transmitted over long distances if compression forces are entirely avoided, and it further permits the employment of iron rods or even wire ropes. The common American type of pumping frame is shown in Fig. 102, where it will be seen that it consists of a

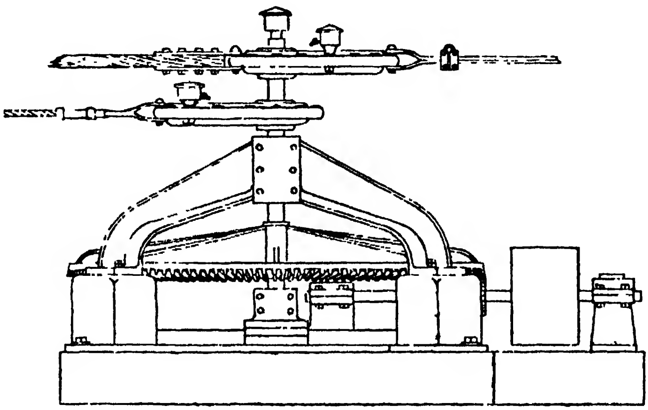


FIG. 102.—COMMON TYPE OF PUMPING FRAME.
Showing wooden, iron rods and wire rope Jerker lines.

central vertical shaft driven by bevel gearing from a horizontal spindle; several eccentrics and straps being attached to the vertical shaft. On the outer flange of the eccentric straps are bored a number of holes for the connection of wrought-iron straps attached to the transmission lines, so that when the shaft revolves the transmission lines are given a slight oscillating motion, as well as a reciprocating, horizontal movement, equal to the throw of the eccentric. From each eccentric are led a number of transmission lines in different directions, so that the power is fairly evenly balanced in practice.

In large pumping stations, where power for thirty to fifty wells is transmitted, a horizontal shaft fitted with eccentrics is often constructed. A heavy wooden band wheel, securely keyed to the shaft, takes the drive by the belt, as well as acts as a flywheel, in storing up energy to smoothly pass the dead centres. The connecting rods attached to the eccentrics have guides working in bushed bearings where the motion is transformed to a horizontal movement.

Considerable care is needed in arranging the work of a large pumping station to deal with forty to fifty wells averaging, say, 1,200 to 1,500 feet deep, in order to equally distribute the load.

Jerker or Transmission Lines.—Until a few years ago, transmission or "jerker" lines were generally composed of timber, and even now this procedure is largely practised. The size of timber used for jerker lines naturally depends upon the power to be transmitted, but they vary from 8 inches by 4 inches on main lines to 3 inches by 2 inches on branch lines. The rods are coupled together by flat sheet-iron straps, through which a few bolts are inserted and tightened up. The jerker lines are suspended by wooden or iron swingers in swing brackets placed at sufficiently close intervals to prevent any undue sag between the points of suspension. Each swing bracket acts as a lateral guide in addition to a support, so that side wind pressures do not deflect the rods far from a straight line. Friction is reduced to a minimum by the attachment of a strip of wood against which the swinger alone rubs if deflected from a straight line. Motion is deflected into any desired direction by occasional bell cranks or change wheels, from which tensional rods are led off in the direction of wells required to be operated.

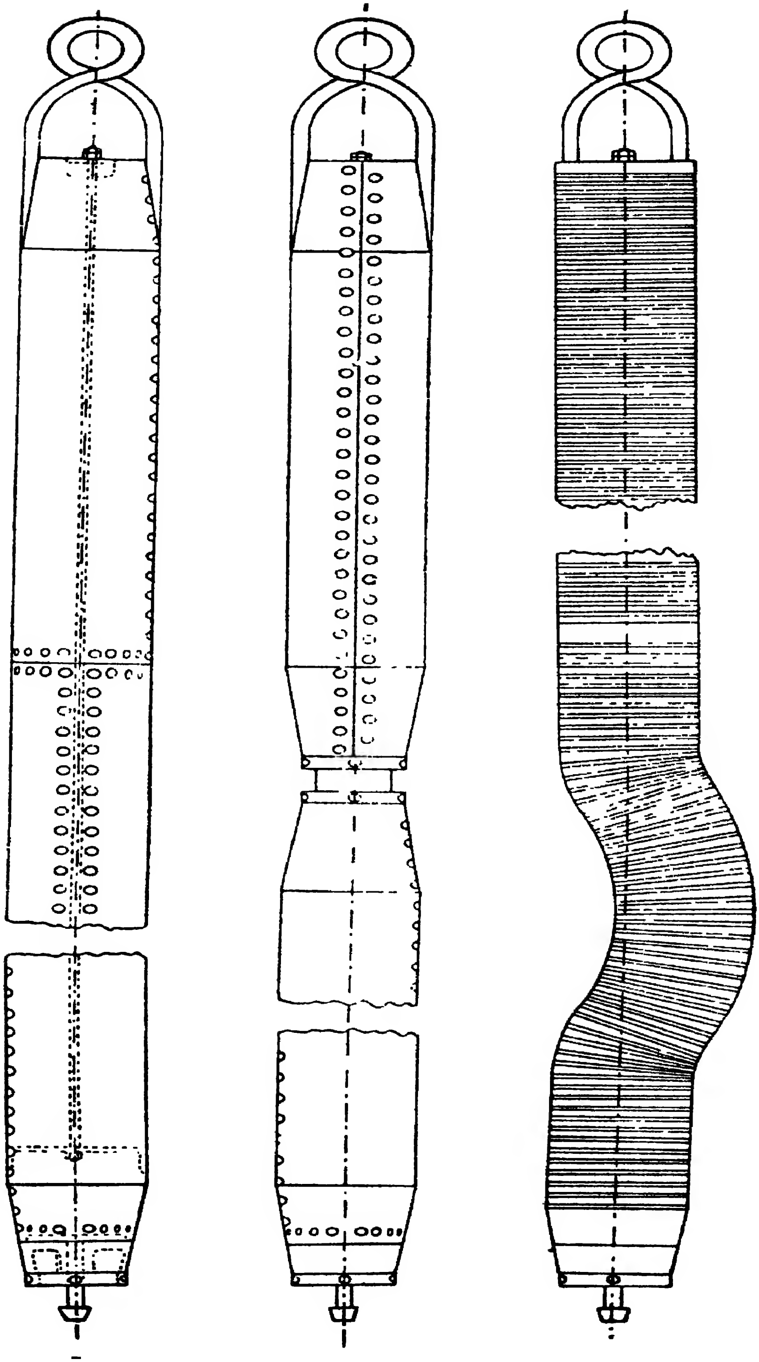
When iron rods are used as transmission lines, they are provided with a clasping device which allows the rods to be quickly coupled together, and provides a projection by which they may be suspended on swingers from suspension brackets. Rope transmission lines are manufactured from thick iron wire,

and are coupled together by special fasteners provided for the purpose.

Bailing.—In some oil-fields, notably those of Baku and Roumania, so much suspended sand accompanies the oil that all apparatus in which plungers and small valves form a part is useless for raising the oil, and it is usually extracted by bailing. The bailers are long cylindrical vessels made of sheet-iron rings riveted and soldered together, fitted with a cast-iron lift valve opening inwards at the lower extremity, and a suspension hook at the upper end. An internally screwed wrought-iron ring is attached to the bottom of the bailer into which is screwed the valve and seating, the valve spindle extending 6 to 8 inches beneath the guide which directs the valve on to its seating. When the bailer is lowered into the liquid the valve lifts and admits the fluid, which fluid passes freely through the vessel so long as it descends, but immediately the bailer ascends the valve closes and the admitted fluid is raised to the surface. By lowering the filled bailer on to a solid base the extending spindle is forced inwards, the valve opens, and the enclosed liquid flows away. Fig. 105 shows the usual arrangement of a well-designed bailing well.

The ordinary bailers vary in diameter from 6 to 14 inches, and from 10 to 60 feet in length, depending upon the diameter of well, depth of liquid, and yield of oil. They are rendered watertight by soldering the joints, and they are fitted with a $\frac{5}{8}$-inch safety rod attached to a cross-bar at the top and bottom of the bailer, so that were the bailer pulled asunder the safety rod prevents the loss of the lower portion. The upper and lower sections are tapered somewhat for guiding the bailer into the well, and protecting the valve and suspension hook.

When a new well is being bailed, immense quantities of sand frequently rise in the well, necessitating constant bailing from the bottom of the well to prevent by its accumulation the total exclusion of the oil, and it is not unusual for the above



described bailers to raise hundreds of tons of sand daily for months at a time before the inlet of sand diminishes. When unattended with water, oil sands are very fluid, closely resembling fresh caviare in appearance, and they readily enter and fill the bailers, from which they also flow with equal ease on the opening of the valve, but a little water with the sand renders the admission to the bailer more difficult, and likewise its extraction may necessitate the removal of the valve and seating to extract the compact mass which forms.

The great length of bailers in some cases is only to give great capacity, but it will be at once seen that any slight deflection of the casing would prevent the free descent of such a long vessel little less in diameter than the well. In Baku the wells frequently become deflected from the vertical as a consequence of landslides, and a large capacity is maintained by using jointed bailers, where the bailer is divided into several sections connected by hollow knuckle joints. Such bailers enable wells with a considerable curvature to be bailed at a profit when they would otherwise be abandoned. Some flexible bailers have been made from flexible metallic tubing connected together in lengths to give the desired capacity. Fig. 103 shows types of bailers used for extracting oil.

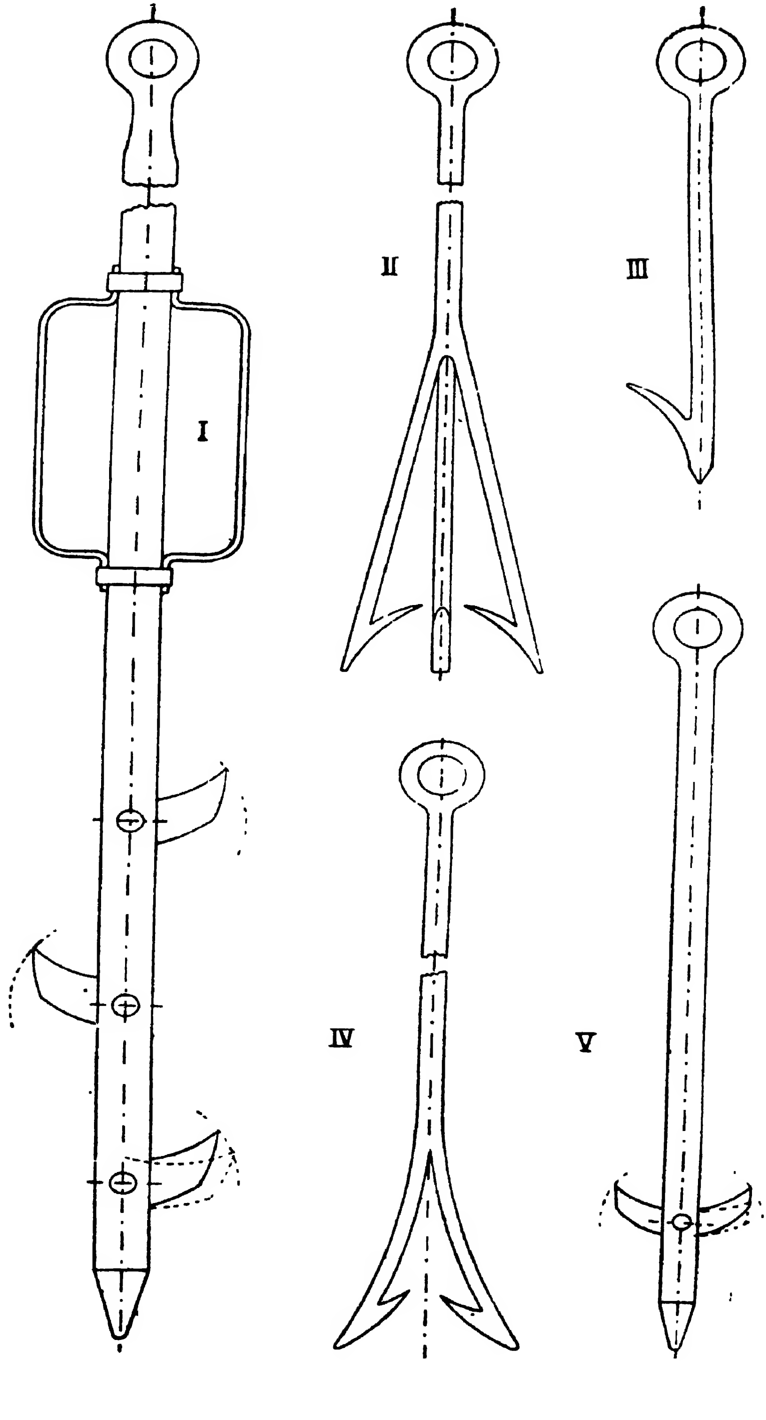
Bailing is conducted by means of a wire rope on a bailing drum of from 10 to 16 feet circumference, to one side of which runs freely on the main shaft a pulley fitted with side friction blocks which fit into a depression on the side of the drum. The main pulley receives its drive direct by belting from the engine, and is drawn by levers towards the drum when it is desired to raise the bailer after its descent by gravity into the well. The speed of bailing is from 1,000 to 1,500 feet a minute, and the power required varies from 30 to 150 horse-power, according to the speed, size of bailer, quantity of water and of sand. Fig. 105 shows the common type of bailing drum.

The bailing ropes are from $\frac{5}{8}$ to $\frac{3}{4}$ inch in diameter, and

they have to be constructed of fine crucible steel wire to withstand the rough treatment to which they are subjected in bailing. Flexibility is neglected in favour of resistance to abrasion, which always takes place through the rope coming into contact with the casing. The rope also suffers severely from excessive and repeated twisting when the high velocity descent of the bailer is suddenly and temporarily checked as it strikes the surface of the liquid, the bailing attendant not being able to apply the brake in time to prevent 30 to 100 feet of rope coiling itself up on the top of the bailer before the latter fills or sinks more slowly in the liquid. For bailing wells of 1,500 feet it is usual to employ a rope of 2,000 to 2,500 feet to allow for periodically cutting off pieces of the rope near the bailer as they show signs of dangerous wear.

The oil is emptied into a "bailing tub" before it flows away to tanks or other receptacles where the sand may settle prior to its removal to the main storage. The bailing tubs are wooden tanks about 6 feet in diameter and 5 feet high, placed on trestles over the mouth of the well. There is a central orifice through which the bailer can pass, and extending to about a foot above the base there is a bored wooden block on the surface of which slides a strip with a sheet iron or copper surface that can be pushed backwards and forwards by an iron rod by the bailing man. When the full bailer has been raised completely from the well the flat sliding piece is pushed over the mouth of the orifice, and as the bailer is allowed by the brake to descend, the valve is pushed upwards and the oil discharges into the tub, from whence it flows away in a chute leading from the bottom of the tub to the settling tanks.

Recovering Lost Bailers and Ropes.—A bailer lost through the breaking of the wire rope or fracture of the suspension hook is recovered by a hook provided with extending spurs lowered on a new rope upon the lost piece, to which it attaches itself and can be withdrawn. If a bailer is torn asunder it is usual to lower a heavy bar fitted with a succes-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sion of hinged protruding dogs, which rise upwards in passing an obstacle in lowering, but extend to a horizontal position when the bar is raised, causing them to firmly grip any object into which they are lowered. Fig. 104 shows several types of fishing grabs used for the purpose.

Power for Bailing.—In the Baku oil-fields double cylinder horizontal steam engines are used for bailing, having the following dimensions :—

Diameter of cylinders	9½"	10½"	11"	12"	13"	14"
Stroke of cylinders	14"	14"	14"	16"	18"	18"
Flywheel diameter	5' 6"	6' 0"	6' 0"	6' 0"	6' 6"	6' 6"
Flywheel face	9"	10"	10"	12"	12"	12"

The larger sizes indicate with 60 lbs. steam pressure as much as 150 horse-power, and will raise a 12-inch by 60-feet bailer at 1,500 feet per minute. The smaller sizes are used for bailers up to 8 and 9 inches in diameter. With the steady exhaustion of oil-fields the level of liquid steadily falls, and in many parts of the Baku fields the wells have now only 20 to 50 feet of liquid, or are even dry at times, although formerly they gave as much as 300 tons of oil daily by bailing, but there are few now which will yield even 100 tons daily owing to the process of exhaustion which is proceeding. From many wells several times as much water as oil has to be bailed to secure a production.

Precautions in Bailing Wells.—When bailing is unavoidable through the presence of much sand with the oil, considerable experience is often necessary to prevent damage to the wells. If a well flows whilst being pumped, nothing serious happens, as the oil flows away from the pump tube or casing heads into the tanks, but when a bailing well is inclined to flow the operator needs to use much judgment for a number of reasons. A discharge of oil from a large diameter well is usually exceedingly violent, and the bailers and wire rope are often ejected from the well with great force if incautiously

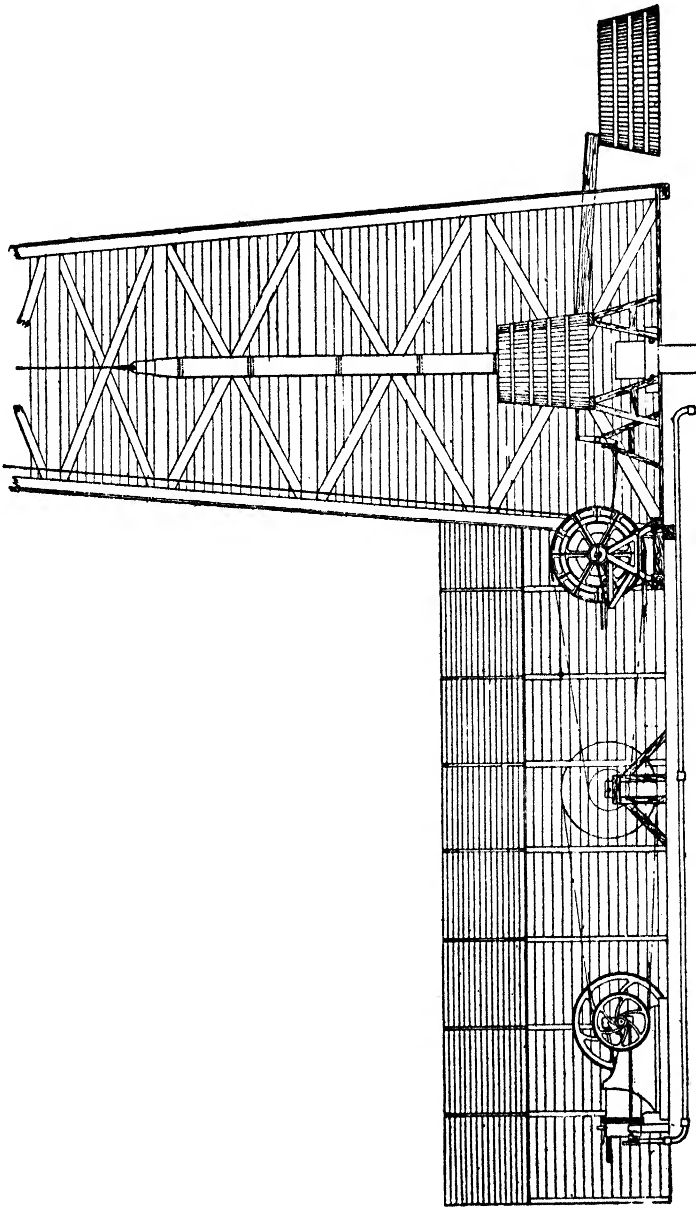

Fig. 105.—General Arrangement of Bailing Oil-Well.
(Shows Gas Engine drawing Gas from Well.)

lowered at a wrong moment. An impending flow or "fountain" is intimated by a gradually rising level of liquid, and when the oil has arrived within 100 to 200 feet from the surface it is usual to take a few bailers from the top to lighten the column, when the well will flow. During a fountain the volume of emitted gas is so great that the operators have usually to abandon the bailing drum and escape into the fresh air, during which time the brake of the drum is securely fixed. The bailer should be lowered very cautiously after a flow of oil, as there is frequently a large mass of loose falling sand which may settle over the bailer and prevent its withdrawal if it is left stationary for a few moments. In the Baku oil-fields it is no uncommon occurrence for several hundred feet of oil sand to run into the well during a single eruption of five minutes, but so fluid is the mass, if uncontaminated with a proportion of water, that the bailers can be raised full of loose sand at each trip until the hole is cleared.

When, as sometimes happens, a flow commences whilst the bailer is near the bottom of the well, the operator should on no account leave the drum, but keep the bailer in slow motion whilst the well is flowing. If the bailer is left suspended in the well near the bottom it may become buried in sand and be irrecoverable, or lead to a lengthy fishing operation, whilst if raised too high it may be ejected from the well, and both the rope and bailer be totally destroyed.

When new wells are bailed, whether intermittent spouters or not, a mass of sand, often accompanied by fragments of rock and clay, collect at the bottom of the well, and unless they are periodically cleaned out they will prevent the free admission of oil. A collection of sand and clay particles can usually be cleared with the aid of the bailer alone by bailing constantly from the bottom, and raising and allowing it to sink rapidly several times before withdrawing to the surface; the suction action caused thereby stirring up the sand and causing it to enter the bailer with the oil on the downward movement. If fragments of clay and rock collect to any con-

siderable extent in the casing they must be cleared with a sand pump.

A new well should never be bailed too rapidly at first, for long experience has shown that the best and longest-lived producing wells are obtained by removing the sand as it flows into the well by almost constant bailing from the bottom for a while. This policy is a trial of patience, as in new wells the liquid bailed from the bottom is so supersaturated with gas that the fluid contents of the bailer are nearly all expelled before the surface is reached. When being drawn through the liquid the contents of the bailer are held down by the pressure above, but the moment the bailer emerges from the fluid the confined gas escapes with violence from the oil and ejects most of the oil from the bailer. In very gaseous wells the bailers are often raised containing only about one-tenth of their capacity of oil, and the explosive ejection of the contents of the bailer as it emerges from the liquid can be heard at a considerable distance. When the level of liquid stands near the surface it is possible to raise the bailer at sufficient speed to witness the expulsion of the oil at the surface.

After the inlet of sand has decreased, bailing is conducted alternately from the top and bottom, and the proportion of top to bottom bailings increased until the maximum safe yield is reached, and neither sand nor water accumulates in the well. If any unexcluded water finds admission to the well, bailing must be continued with caution, as the oil sands, unless kept free by much gas, set very hard when mixed with water, and may partially seal the oil source. When such is the case the level of oil falls, and there is a risk that the unexcluded water will increase in volume, making it still more difficult to keep the plug free, and render more frequent bottom bailing necessary to remove the increased quantity of water. Failure to adopt these precautions generally leads to the loss of the well, consequently prudent producers suppress their impatience and rest content with a smaller production for a while.

Cost of Bailing Wells.—As fuel forms the chief expenditure in bailing, the cost of bailing largely depends upon the value of the fuel. The expense of labour, wire ropes, bailers, and stores do not much vary in different wells, and the average cost of bailing an average Baku well amounts to about £4 a day, with fuel at 25 copecks per pood (33s. per ton). On an average production of 16 tons a day this works out to about 5s. 3d. per ton.

The average power taken by bailing wells using electric power in the Baku oil-fields in 1908 was about 16 kilowatts (21.5 H.P.) per hour or 11,500 kilowatts (15,500 H.P.) per month. With oil at 20 copecks pood (26s. per ton), the cost of power is 7 copecks (1¾d.) per kilowatt hour, and the monthly cost of power for bailing an average well by electricity was 805 roubles (£85), equal to about 2¾ copecks pood (3s. 8d. per ton) in a well producing 1,000 poods (16 tons) daily.

Air-Lift Process of Raising Petroleum.—The successful operation of the air-lift process of raising water naturally attracted attention towards its application to petroleum, but the conditions are quite different with the latter fluid, and many complications arise. For raising water efficiently compared with pumps it is essential that the direct lift should not exceed 50 per cent. of the total submergence of the air inlet in the water; that is, if there were 400 feet of water in a well, even if the air were admitted to the rising main at the bottom of the well it could only be raised with economy 50 per cent. of 400 feet = 200 feet. With petroleum much the same conditions must exist for efficient working, but there are few oil-fields in the world where there is sufficient oil in the wells to permit of the general adoption of such a process.

The Baku oil-fields, previous to the year 1905, offered an excellent field for air-lift, as there were many wells with a high level of liquid of too small a diameter to bail with success, and containing far too much sand to allow of pump-

ing, which were capable of yielding from ten to fifty times their bailed production. In 1899 the first experiments with air-lift in the Russian oil-fields were made under the supervision of the author, and in the first well tested under unfavourable conditions, a daily yield of 40 tons was obtained from a well which gave less than 8 tons daily by bailing, whilst the extra fuel consumption did not exceed 1.5 tons of oil daily.

The usual method is to lower a column of 4-inch tubes to the bottom of the well—about 10 feet of the lowest tube being perforated with ½-inch holes—into which is lowered a 2 to 2½ inch column. This latter column, which represents the rising main, is sunk until it is submerged to a depth in the fluid equal to at least twice the distance from the level of the liquid to the surface. Suitable attachments are fitted at the surface, and air is led down the space between the two tubes so that it rises in the centre tube, aerating the fluid in the tube as it enters. The working air pressure approximately corresponds to the weight of the column of liquid representing the submergence, and the supply of air is adjusted to produce sufficient aeration to cause the liquid to flow in a constant stream at the surface.

The air-lift is only started by considerably exceeding the working and calculated air pressure, in consequence of the friction of such a long column of viscous oil, the force necessary to overcome inertia, and the only partial aeration of the column; indeed, the first discharge after admission of air is exceedingly violent, owing to the formation of a piston of air beneath a long column of unaerated fluid. Variations of the oil level are indicated by fluctuations of the air pressure gauge at the mouth of the well, where it is customary to have one pressure gauge on the compressor side and another on the air-lift side of the valve which adjusts the air admission.

If the fluid in the well falls, the discharge becomes intermittent, but can, if small, be made continuous by increasing the volume of air. There is, however, a limit after which a

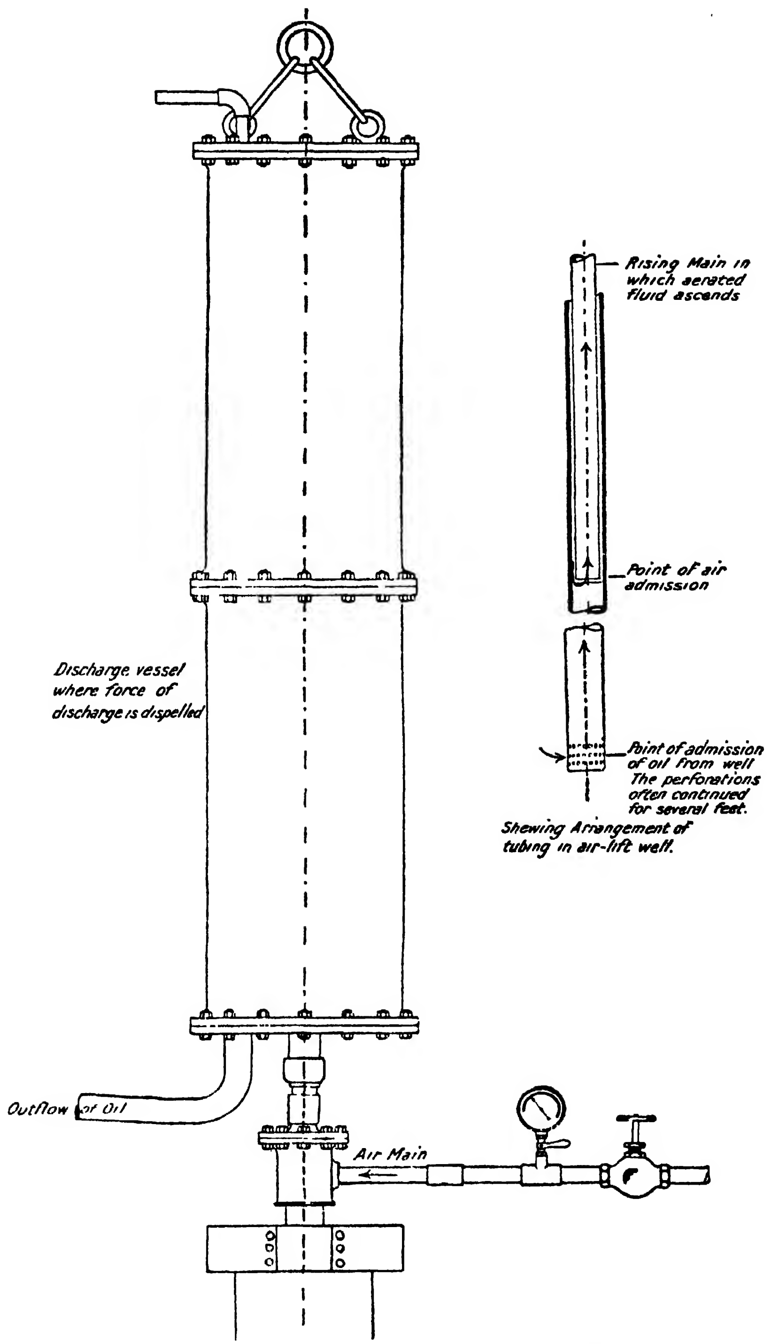

FIG. 106.—COMMON ARRANGEMENT OF AIR LIFT

continuous discharge cannot be induced, and the action either proceeds intermittently, each outflow of liquid commencing with a full bore flow of unaerated oil followed by a violent discharge of gas and oil spray, or the discharge takes the form of a constant spray. With the intermittent or spray action the efficiency of the plant falls enormously, as will be seen from figures below, but, nevertheless, the cost of its working is many times repaid in special cases.

Most Russian wells yield a certain proportion of water with the oil, and often a considerable amount of sand is raised in addition; indeed, its removal, as has already been explained, is usually necessary to keep the well from "plugging." The aeration and violent agitation of oil and water in certain proportions leads to the occasional formation of emulsions, some of which defy all simple measures of separation. Some emulsions are discharged from the air-lift in congealed grey masses of the consistency of butter, whilst others are fluid and have the consistency of cream. Many such emulsions liquefy and separate in a few minutes, but some containing 30 per cent. of water neither separate after lengthy settlement in open tanks nor even permit of any mechanical separation. This latter class of emulsion is not common, and usually producers are not much troubled by its formation.

Great quantities of sand sometimes cause the air-lift to work erratically for a while and may entirely stop its action, but usually the sand eventually gets freed and steady working is resumed. At such times the author has seen a thick fluid containing over 50 per cent. sand discharged for hours before the well was cleaned and normal working recommenced.

The gas accompanying the oil considerably modifies the action of an air-lift, both by diminishing the theoretical air pressure required and by assisting the aeration, and if a packer is attached to the tubing in order to compel all the gas to pass with the oil up the rising main, the amount of

air required to sustain a discharge may often be reduced considerably.

In some air-lift wells in Bibi-Eibat a diminution of output led to the extraction of the 2½-inch rising main tube, when it was found to have a deposit over half an inch thick on the inside of the tubes. The incrustation was chiefly hard carbonate of lime, and was evidently due to a steady deposition from the water accompanying the oil as a result of the liberation of carbon dioxide following the aeration and agitation the liquid suffered during its ascent.

The air-lift process can with advantage be employed for raising oil under the following circumstances when pumping cannot be adopted :—

(*a.*) When the diameter of well is so small that the quantity of oil obtained by bailing is much less than the well is capable of yielding.

(*b.*) When the influx of sand and water in a deep well makes it compulsory to bail almost entirely from the bottom, consequently reducing the yield.

(*c.*) When a bailing well becomes so damaged or deflected that only short, small bailers can be used.

(*d.*) When a sufficient head of liquid is maintained to satisfy requirements as to submergence.

When the best submergence is secured, an air-lift plant will give about 1 volume of liquid for each 11 to 12 volumes of free air, *i.e.*, a well taking 200 cubic feet of free air a minute will discharge about 16 cubic feet or 100 gallons a minute. When the liquid falls to give only a 50 per cent. submergence, the ratio increases to 1 volume of liquid to 20 and 25 volumes of free air, and in one case under the author's observation, where the submergence was only 35 per cent., the ratio of liquid to air was 1 to 44.

The air compressors used for air-lift pumping are of the compound type, capable of working regularly at 350 lbs., but in which the pressure can be temporarily raised to 500 lbs. per square inch. The usual compressors chosen have an

output of 300 cubic feet of free air a minute at normal speed, and one machine is capable of operating one well under the best conditions of submergence, &c.

Compressed Air Systems of Raising Oil.—Quite distinct from the air-lift whose normal action is correctly due to the lightening of the column by aeration, are systems in which air in volume is used to expel the oil. Strictly speaking, the air-lift is no longer pure aeration of the fluid when it commences to work intermittently, and the liquid is expelled in mass by volumes of ascending air, and similarly when oil is discharged in the form of a spray the action is that of an ejector. In the United States the periodical introduction of compressed air to the bottom of wells of small diameter which yield little or no sand is often practised with success, each admission of air causing the well to flow. The quantity of air and periods of admission naturally vary with the diameter of well, amount of gas, and level of liquid, which latter also determines the pressure of air necessary.

Compressed air can be employed for raising oil from low level wells by the following means, introduced into the Russian oil-fields by Mr R. Stirling, M.I.C.E.:—A column of 2½ to 3 inch tubes, near the bottom of which is attached a receiver of enlarged tubing, is lowered into the well so that the larger tubing is entirely submerged in the oil. The lower 10 or 12 feet of the tubing below the receiver is perforated to admit the oil freely, and at the lower junction between the receiver and tubing is attached a ball valve on a seating. An inch pipe inserted inside the 2½ or 3 inch tubes conveys the air to a point immediately above the valve, so that by admitting the air to the inch pipe, the ball valve is forced upon its seating and the accumulated oil in the receiver and rising main is driven to the surface. A violent escape of air ensues as the last portion of the oil is ejected, and on the release of pressure the fluid from the well rushes into the receiver and rising main from the well. The dis-

charge is made to actuate a device which automatically shuts off the air, whilst another arrangement admits the air at intervals the periods of which can be adjusted to suit requirements. The cost of such systems far exceeds pumping both in initial outlay and upkeep, and its employment is restricted to special cases where for some reason other methods of oil extraction are unsuitable.

Raising Petroleum by Absorptive, Endless Band.—A process has recently been invented and patented by an Austrian engineer whereby oil is raised from wells by a specially manufactured, absorptive, endless band which is caused to descend and ascend from the well at a high speed. The band is led into the well by pulleys actuated by gearing on a frame at the surface, and the fluid which clings to the prepared material is abstracted by the passage of the band through rollers as it emerges from the well. The band is made of strong material, and the absorptive nap is sewn on in such a way that it can be renewed if it becomes rubbed off in places.

It is claimed that the process can be used for wells of any depth and for any class of viscous fluid, and not only can the fluid itself be raised economically but also sand and suspended matter which commonly accompanies oil. A band 3 inches wide running at a speed of 3 feet a second will raise, it is claimed, as much as 4,000 lbs. of oil an hour, but the actual rate of removal of fluid can be accurately adjusted by the speed of the roller. So far only experimental plants have been tested in Galicia, but the system appears to justify an exhaustive trial where the action of pumps is impaired by a prevalence of suspended sand.

Cleaning Oil Wells.—In oil-fields where the oil contains a large percentage of solid hydrocarbons (paraffins) a deposit of paraffin wax forms on the tubing and round the bottom of the well, until eventually the entry of petroleum is entirely

excluded unless measures for its removal are undertaken. The hydrocarbons are always soft, and can be easily scraped from the pump tubing, but it is often necessary to lower some form of tool to clear the paraffin from the well. The scrapings are always preserved, as they constitute a valuable commercial product. In some of the Texas oil-fields a similar deposition of sulphur has, it is reported, led to the adoption of cleaning measures to keep the wells open. In some of the eastern oil-fields of the United States the removal of the paraffin is brought about by steaming the wells for a while or pumping down hot water.

There are few oil-fields where wells do not suffer some loss of production through silting after a time, and in many countries periodical cleaning must be undertaken. Where pumping is the method adopted for raising the oil, it is a common and very excellent practice, where possible, to drill the well about 40 to 50 feet below the oil source, when the hole thus left acts as a receptacle for any detritus or sediment which enters the well but is not extracted by the pump.

Petroleum is only raised by bailing when pumping is impossible on account of considerable quantities of sand, and such wells often require periodical cleaning to allow free admission of oil. When no water is present with the oil the bailers themselves will keep the well clean, as sand enters the bailer with the oil and is raised, but where there is a proportion of water the incoming sands often form a cement-like mass which excludes the free entry of oil into the well and defies ordinary methods of cleaning. In such cases, when a hard plug has formed some distance up the casing, a heavy steel-pointed pick is lowered on a wire line and is raised and dropped a number of times to loosen the sand, followed by a sand pump which draws the sand into the vessel.

In some fields, as Russia and Roumania, hard, arenaceous nodules find their way into the well in large numbers, and these have likewise to be removed with a pick and sand pump if they accumulate to an injurious extent.

CHAPTER IX.

Sources of Energy on Oil-Fields.

Considerations affecting the Choice of Power for Petroleum Prospecting—Considerations affecting the Choice of Power for Oil-Field Development—Steam Boilers—Steam Economising Devices—Steam Engines—Oil Engines—Gas Engines and Gas Power—Electric Power.

Considerations concerning the Choice of Power for Petroleum Prospecting.—To one unacquainted with oil-field work the selection of the best kind of power to be employed for prospecting purposes appears of little concern, but in practice much consideration should be given to the subject unless disappointment is courted. Steam is, and has always been, the favourite source of energy, chiefly on account of the simplicity attending its generation and utilisation, as well as the flexibility of the steam engine. No motive power requires less skill and attention than a steam engine, nor will any motor better withstand the rough treatment to which machinery is usually subjected in pioneering, where skilled artisans are rarely to be found.

When prospecting is undertaken in a region far removed from railway communication or even macadamised roads, the transport of a heavy steam boiler is a costly matter, and one naturally considers other and more compact sources of motive powers, especially if fuel is not locally procurable. If water and either wood, coal, oil, or gas fuels can be obtained locally at a reasonable cost, a steam engine and boiler should be certainly chosen for prospecting unless the transport difficulties are almost insuperable. Where water is scarce and solid fuels are expensive and perhaps difficult to obtain at any cost, the question of internal combustion engines is

naturally raised, and these may with advantage be used in certain circumstances. For reasons which are given elsewhere (see p. 312), internal combustion engines are not suitable for all systems of drilling, and where their employment is practically unavoidable, it may be advisable to change the form of rig to suit the type of power. Electrical power is usually removed from the province of probability for prospecting owing to the high initial outlay a generating plant implies before the commercial worth of a district has been demonstrated. Where, as is frequently the case, small quantities of crude petroleum can be extracted from hand-dug pits, certain types of oil engines can be employed with suitable drilling apparatus.

Considerations affecting the Choice of Power for Oil-Field Development.—Not quite the same considerations influence the choice of power on a working oil property as on a prospecting venture where a certain amount of uncertainty as to the future exists. The scarcity or prevalence of fresh water or water of any character in the vicinity largely influences the choice of power, although such features as means of transport, character of ground, and topographical details have an important bearing on the case. In many oil regions fresh water is very scarce although there is an abundance of salt water, whilst in other cases local waters are so contaminated with salts in solution and organic impurities that their direct employment in steam boilers is attended with great risk.

The relative cost of wood, coal, and oil, and the existence or absence of natural gas affects the problem of power considerably, whilst the system of drilling dictated by local conditions largely influences the choice of power. The climatic conditions, distance apart of individual wells, and average time taken to complete wells in the district also enter into one's calculations when deciding upon the nature of power to be adopted. Sometimes conditions justify the installation of

evaporators for the production of fresh water from sea or other bad water for employment in boilers, consequently brief particulars of such plants are given in a subsequent paragraph. The use of electrical power for oil-field work is extending, but its general adoption has been delayed by the disregard of manufacturers of electrical plant to consider the peculiar duties the motors have to perform whilst ensuring safety, economy, and reliability.

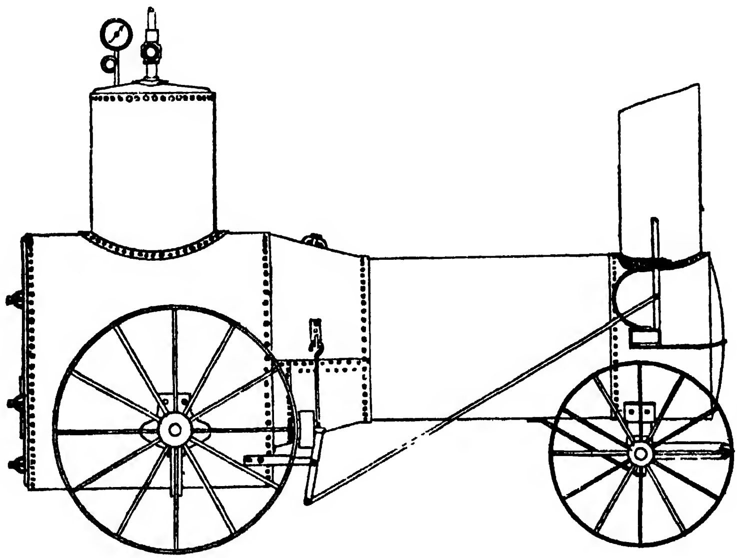

FIG. 107.—AMERICAN TYPE OF PORTABLE OIL-FIELD BOILER.

Steam Boilers.—Where there is a moderate supply of fresh water the use of a multitubular portable boiler is customary for oil prospecting work. Special portable boilers, often known as the Colonial type, are made in sizes for evaporating from 800 to 1,500 lbs. of water per hour, provided with an extra large fire-box suitable for burning wood or liquid fuel if occasion demands. They should be furnished with injector, feed pump, and forced draught jet, and be sent out with spare boiler tubes, also firebrick furnace attachments and liquid fuel burner if the burning of liquid fuel is probable.

Lagging should not be omitted to reduce radiation losses; fusible plugs should be included, and high-class fittings provided throughout.

For an ordinary American cable or Canadian drill, a boiler of 1,000 lbs. per hour capacity under normal working is sufficiently large, but where the climate is very cold, the wells deep, or additional steam is required for subsidiary power, as pumping water or driving electric light motor, a larger boiler should be used. When using rotary water-flush systems of drilling, where the casing or tools have to be rotated and a pump worked under high pressure at the same time, a boiler should be used capable of evaporating easily 1,200 to 1,400 lbs. per hour.

The following are particulars of portable boilers made by Messrs Ruston & Proctor, largely employed for oil prospecting and development all over the world.

PARTICULARS OF MESSRS RUSTON & PROCTOR'S DRILLING BOILERS.

Heating surface - -	200 sq. ft.	241 sq. ft.	254 sq. ft.	294 sq. ft.
Grate area - - -	10.14 ,,	12.25 ,,	12.25 ,,	12.25 ,,
Evaporation in lbs. per hour - - - -	1,000 lbs.	1,100 lbs.	1,150 lbs.	1,320 lbs.
Weight with chimney, wheels, fittings, undergear - - - -	77¼ cwt.	97 cwt.	97 cwt.	104 cwt.

The boilers will evaporate about 8 to 9 lbs. of water per lb. of average coal. When wood is used the boilers consume between 3 and 6 cords of wood a day of twenty-four hours, or 13.5 to 27 cubic feet of stacked wood per 1,000 lbs. of steam. When oil fed the boilers will consume from ¾ to 1½ tons of oil per day of twenty-four hours, or if gas is used somewhere about 2,000 cubic feet per hour should be allowed. Such multitubular boilers will evaporate about 5 lbs. of water per square foot of heating surface and consume about 18 lbs. of coal per square foot of grate surface per hour. Fig. 108 shows a typical boiler made by Marshalls.

When portable boilers are used they are generally placed as near as possible to the engines, which latter are usually sufficiently far from the bore-hole to avoid ignition of any ordinary quantity of gas which may be evolved during drilling. If strong gas is suspected the boilers must not be located near the well.

One common type of American boiler used on the American oil-fields is known as the Californian boiler. It consists of an ordinary cylindrical tubular boiler arranged so that when mounted on masonry or iron framework the firing

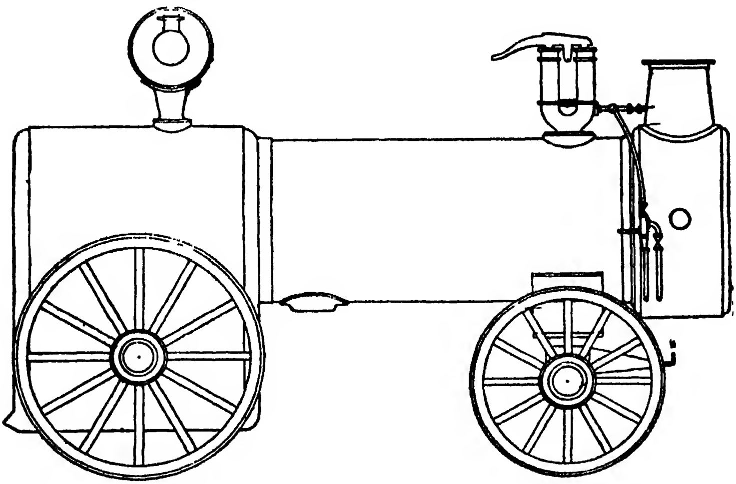

FIG. 108.—ENGLISH TYPE OF PORTABLE OIL-FIELD BOILER (Marshall & Sons).

is performed beneath, the flue gases after passing the length of the boiler being led through the tubes from the back to the point where the smoke stack is located. These boilers are made in sizes from 25 to 45 nominal H.P., and are largely used in the oil-fields of the States. Needless to say the multitubular type of boiler must never be used with salt or dirty waters.

In many oil regions the use of high evaporative boilers is prohibited by the absence of fresh water, and either locally obtained saline water or sea water has to be used. In such

cases, steam is usually generated in either Cornish or Lancashire boilers at a pressure which should never exceed a maximum of 60 lbs. per square inch. Such boilers of sufficient size to supply steam for even one drilling well are too large and heavy for portability on wheels, and they are either set in a masonry structure or in a sheet-iron frame, which can be lined with firebrick, so that the flue passages pass along the bottom and sides of the boilers.

A fixed boiler of the above description has many disadvantages, apart from its weight and size, which render its transportation expensive when oil prospecting is proceeding. Its erection is not only expensive, but much time is occupied in the work. Its range of effective action is limited, as condensation, especially in cold climates, makes it impossible to supply sufficient steam at the required pressure for a radius exceeding a certain limit. The evaporative efficiency is low, especially as a heavy scale accumulates after a short period under steam, and about 30 per cent. of the water fed to the boiler has often to be blown off to keep the density within the limits of safety. Then, in addition, there is the ever present danger of a collapsed flue or burnt plate, either through inattention to regular blowing off, or to the period between successive stoppages for cleaning being exceeded.

In the Baku oil-fields of Russia, Caspian sea water was, until the use of electricity commenced in 1900, practically the sole source of power, and even in 1908 three-fourths of the power was generated in Lancashire boilers fed with sea water. Practically no fresh water is to be found within many miles of the Apsheron oil-fields; indeed, the 100,000 inhabitants of Baku are provided almost entirely with condensed water obtained from evaporators. The defects of such a system have long been recognised, but as the wells are located near together, and it is inadvisable and illegal to have a boiler near an oil well, the continuation of the system is more excusable than would otherwise be the case. Nevertheless, the waste of fuel as a result of the existing defective steam

systems is enormous, and the high prices of crude oil are compelling producers to seek cheaper sources of power. The author has found that the average nominal 45 H.P. Russian Lancashire boiler, 6 feet 6 inches diameter by 30 feet long, and heating surface of about 750 square feet, will only produce, under normal conditions, less than 10 lbs. of steam per lb. of crude oil fuel having a calorific value of 20,000 B.T.U. per lb. The loss in distribution through long steam mains on account of friction and condensation is so great that when the average air temperature is 80 deg. Fahr., the consumption of fuel is between 5 and 6 lbs. per brake H.P. per hour, whilst in winter the consumption exceeds these figures. So excessive is the wear and tear on boilers using sea water, and so great the waste of fuel as a consequence of its use, that the author's firm in one case installed, with considerable success, where there was no fresh water, an evaporating plant, and used fresh water in multitubular boilers on an oil property where the operations extended over several square miles. Where sufficient gas is available for fuel, and there is an ample supply of sea water, this course can always be successfully introduced.

In some regions where only sea water is available, plain cylindrical vessels have been used as boilers, the heat being applied by firing below and leading the gases along the sides of the vessel also. Such boilers admit of easy cleaning, but their evaporative efficiency is exceedingly low.

In Russia, Roumania, Galicia, Texas, and other oil-fields, where the wells are placed close together, the steam boilers are arranged in batteries of six, twelve, or more, the steam being conducted about the properties by well-insulated mains. Where large quantities of gas are emitted by the wells, stringent laws are often enforced regarding the position of boiler-houses, and their relation to oil wells, and steam is often led long distances with consequent considerable losses.

Steam Economising Devices—*Feed Water Heaters.*—

Where batteries of boilers are erected, it is now customary to introduce feed-water heaters (economisers), superheaters, and other devices to save fuel, especially where salt water is in use with its accompanying serious waste of fuel. When fresh water is fed to boilers, the feed-water heaters can be placed in the flues, but when the feed is salt water, or other very hard and untreated water, exhaust steam only should be used, or a deposit of lime or other salts will form and choke the feed heater. By heating feed water from 60 to 180 deg., a saving of over 10 per cent. in fuel can be obtained, besides reducing the strains imposed on a boiler by feeding cold water. When no special feed-water heaters are available, it is a common plan to allow the feed water to fall in a spray through a vessel into which the exhaust steam pipe from the surface is led, the steam being thereby partially condensed, and the water raised in temperature. In such cases means should be taken to remove all grease or oil from the water.

Feed-water heaters need no description, as they are now made by nearly all firms interested in steam plants.

Superheaters.—Superheaters have been greatly simplified of late, and can now be purchased in units which permit of addition or abstraction of sections as occasion warrants. The steam from the boiler is led through a series of tubes exposed to the flue gases before it enters the main steam pipe, the temperature thereby being raised some 400 to 500 deg. Fahr. above that due to the steam pressure. The saving resulting from the introduction of superheaters where there are long mains is considerable, as practically dry steam can be conveyed long distances. The superheat is rapidly lost unless the steam mains are well lagged with insulating material, which latter must not be of a combustible nature.

Condensers.—The greater attention to fuel economy has led operators in many districts, where salt water is used for the generation of steam, to take measures to recover their exhaust steam for use as fresh water feed, instead of salt water, and where there is a large supply of water of some

kind, this plan can often be introduced with considerable success. Salt water causes losses in a variety of ways. There is often a 30 per cent. blow-off to keep the salinity down to workable limits of safety, periodical stoppages for cleaning, and great evaporation losses through the formation of scale on the furnace tubes and boiler shell. The total loss of fuel as a result of using water of ocean salinity cannot be less than 20 per cent. under normal working, and producers are now taking measures for the condensation and use of exhaust steam.

The subject has been simplified by the manufacture of compact, light condensers of great efficiency and suitability for oil-field work by the Liverpool Engineering and Condenser Company under Quiggin's patent. An inexpensive Quiggin's condenser suitable for condensing 10,000 lbs. of steam per hour only weighs 30 cwt., and will condense 40 lbs. of steam per square foot of cooling surface at atmospheric pressure with a consumption of only 15 lbs. of cooling water per lb. of steam. By coupling up an exhaust main to a number of steam engines, pumps, or other steam using contrivances, the whole may be condensed and returned as feed to the boilers after treatment for the extraction of grease.

Where water of any kind is very scarce, aero-condensers are sometimes used, and in 1908 a special portable type was designed for a district where there was little water available, and the climate was tropical. The steam was led into a radiator of special form, and air was impelled past the radiator by a fan running in ball bearings fitted to the framework. The condenser weighed complete 168 lbs., and condensed 480 lbs. steam per hour, with an expenditure of 1.5 H.P. on the fan. The results of a trial were as follows:—

Revolutions of fan per minute	880
Power for driving	1.5 H.P.
Temperature air at inlet	96.8 deg. Fahr.
Temperature air at outlet	159.8 deg. Fahr.
Temperature of condensed water	200 deg. Fahr.
Water condensed per hour	480 lbs.

Evaporative condensers are often erected in places where there is only a limited supply of fresh water. Exhaust steam is led through a series of tubes, usually built up in units, on the outside of which a steady stream of water is allowed to trickle. The rapid evaporation of the water coming into contact with the hot tubes causes condensation of the steam. By using evaporative condensers 100 lbs. of steam can be condensed with a loss of two-thirds of 100 = 66 lbs. of water. If impure or salt water is used for evaporative condensers, a deposit accumulates on the tubing, impairing the efficiency, and making it necessary to take measures to secure its removal.

All surface condensers require a considerable quantity of circulation water, and if there is a scarcity or it has to be pumped some distance or height from its source to the condensers, it is good practice to erect cooling towers. Cooling towers can be cheaply constructed of timber, the hot water leaving the condensers being pumped to a chute from which it trickles down over a number of baffles through which air circulates. The evaporation of a small proportion of the water causes the rapid cooling of the remainder to the temperature of the air, so that it can be used over and over again, the loss alone being made good by added water. If the loss during the operation from all sources is 10 per cent., only 10 per cent. of the quantity of circulating water is needed after the first supply has been pumped up. In tropical climates the loss through evaporation may exceed 10 per cent., but in temperate climates the loss will rarely exceed that amount.

Evaporators.—The preparation of distilled water from impure water was at one time an expensive operation, as 1 gallon of pure water could only be obtained from the direct evaporation of 1 gallon of impure water, the heat of the steam being imparted entirely to the circulating water of the condenser and wasted. Modern distilling plants are multiple in effect; that is, the latent heat of the steam is utilised in

evaporating other water at a reduced pressure, and the new steam generated is again employed for evaporating still more water at a further diminished pressure.

There are many such evaporators in the market now, which, by multiplying the effect, the following results can be obtained from the evaporation of each gallon of water :—

Single effect	1.8 gallons	of water per	gallon of water	directly evaporated
Double effect	2.4	,,	,,	,,
Treble effect	2.9	,,	,,	,,
Quadruple effect	3.3	,,	,,	,,

From the above it will seen that with an evaporation of 14 lbs. of water per lb. of oil fuel, 1 lb. of oil will produce 4.6 gallons of water in a quadruple effect plant.

The last evaporator units are worked under a high vacuum to reduce the temperature of evaporation, and the dense impure water which passes in succession through each unit is drawn off the last evaporator by a brine pump. The feed-water and air pump exhaust into the condenser, and the evaporators are made in such a way that the deposited salts can be easily cleaned out at intervals.

Steam Engines.—The most common type of drilling engine is a horizontal, single cylinder reversing model of strong make, with few polished and finished parts. The dimensions of engines in most common use in the United States, Roumania, Galicia, East Indies, and in other oil-fields are as follows :—

American Dimensions.

Size.	Weight.
8 in. by 12 in.	2,300 lbs.
9 ,, 12 ,,	2,600 ,,
10 ,, 12 ,,	3,000 ,,
11 ,, 12 ,,	3,500 ,,
12 ,, 12 ,,	4,300 ,,

English Dimensions.

Size.	Weight.
10½ in. by 14 in.	3,800 lbs.
11 ,, 14 ,,	3,920 ,,
11½ ,, 14 ,,	4,050 ,,

For wells of ordinary dimensions and depth, *i.e.*, those with a starting diameter not exceeding 12 inches and a finishing depth of 2,000 feet, the 11 by 12 inch or 11 by 14

inch engine is large enough, but for extra large diameter wells, such as those of Russia and Roumania, which usually have a commencing diameter of 24 to 36 inches, a very much larger engine is required. The Baku drilling engines are of of the horizontal double cylinder, non-reversing type with cylinders 12 by 16 inch stroke, the exceptional size being due to the general use of the low initial steam pressure of 60 lbs. per square inch, and frequent reduction of this to 20 or 30 lbs. through friction and condensation in long mains.

With the American cable and some other system of drilling it is necessary to have a reversing engine, but no reversing gear is required for some systems. The distinguishing features of a drilling engine consist in the attachment of an equilibrium valve which enables steam to be admitted or excluded from the cylinder by pulling or slackening a cord which leads to the operator in the derrick, and in the case of a reversing engine a means of instantly reversing the engine by means of a cord. A pump and exhaust steam feed-water heater is, as a rule, fitted to drilling engines, whilst governors are always omitted, and no needless weight or finish is given. It is the exceeding lightness, combined with strength, that has given to the American engine such a wide reputation.

No motor is as suitable for cable drilling as the single cylinder steam engine. The extreme sensitivity of such an engine, which immediately responds to variations of power when thrown on or released, makes it peculiarly adapted for cable drilling. During the downstroke of the cable tools the engine races, and allows the harder hit which is required, whilst on the upstroke, when the weight of the tools is taken, the engine slows up, thus avoiding the great strain which would otherwise be transmitted to the cable as in the case of a motor running at constant speed. So much importance is attached to this flexibility of the engine in drilling that it is usual to construct the flywheels of drilling engines in such a way that additional rims can be added or removed to suit the depth of well, weight of tools, or speed of running.

PLATE XXII.

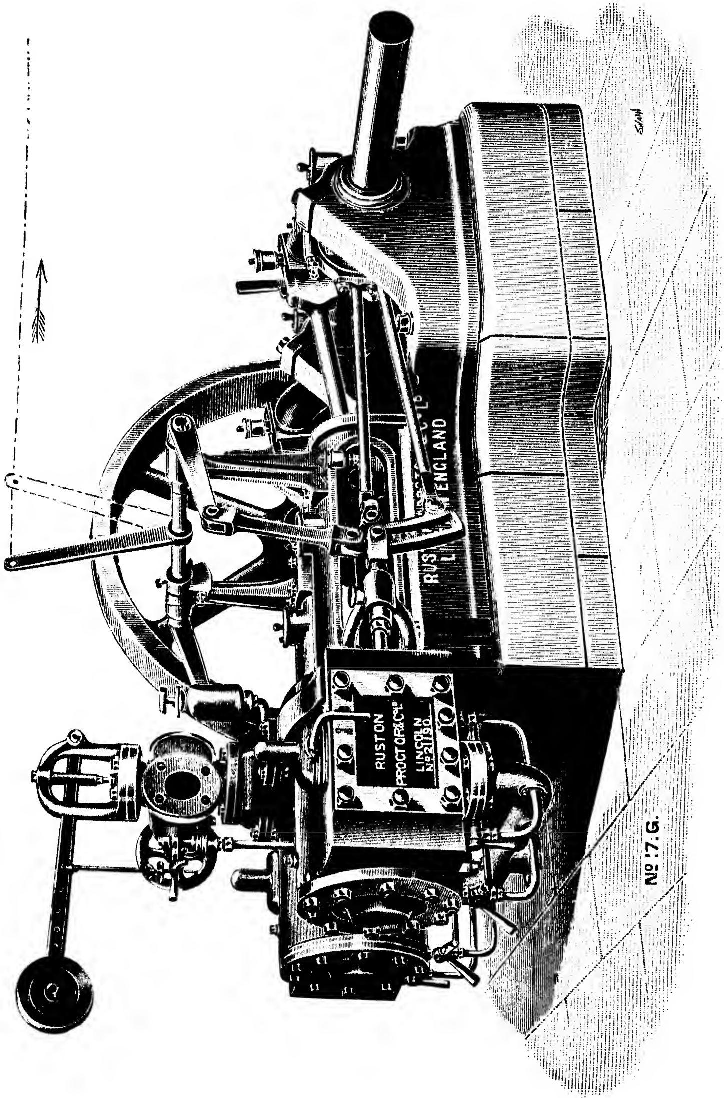

FIG. 109.—A DOUBLE-CYLINDER REVERSING DRILLING ENGINE BY RUSTON & PROCTOR.

[*To face page* 312.

Oil Engines.—The use of oil engines for oil-field operations is steadily advancing, but there are naturally some purposes where a frequently repeated reverse direction is required for which oil engines are not suitable. Internal combustion engines are not convenient for drilling as they run at a constant speed, and can neither be reversed nor forced without serious loss of efficiency, if circumstances demand; but where difficulties practically preclude the possibility of employing steam, they can be used with some forms of drill, and have many times been put to practical use in drilling wells. For steady work, such as pumping or bailing wells, generating electric light, pumping water or oil about the field, and driving other subsidiary plant, oil engines can be employed with considerable economy over steam.

The purchase and installation of an oil engine approximates in cost that of a steam installation with boiler, but, on the other hand, there is a much less margin of reserve power in the former than the latter. For powers exceeding 50 H.P., oil engines become bulky, and some difficulty is often experienced in starting them; indeed, it is always advisable to have a small oil engine, or some other power, for putting them in motion.

For oil-field duties the crude oil engine is favoured, and the common necessity for heating up the vaporisor to a high temperature—as is usual in this type of engine—by a lamp, which would be accompanied by too much danger in some situations, is overcome by starting the engine cold on benzine, and continuing until the vaporisor reaches the requisite temperature to run on crude. Crude oil taken direct from the well should be allowed to stand a while for the separation of water and sand before it is led to the engine, and in any case the employment of crude necessitates the periodical cleaning of the vaporisor to remove the deposit of carbon which always accumulates near the injection spray.

Where the local waters are excessively charged with lime or salt, the cooling water should be obtained from a different

source, or condensed water should be used, and the loss by evaporation periodically made up. The author's attention has several times been directed to accidents which have originated from the cooling chambers and circulation pipe becoming furred up with salt and lime, and consequent overheating of the cylinders. In tropical climates the capacity of the circulation water tanks should be considerably increased, and special provision should be made for automatically recording a fall of water which would cause the circulation to cease.

A crude oil engine consumes only ¾ lb. oil per horse-power per hour compared with 2¼ to 3 lbs. for a steam engine under usual oil-field conditions, but more skilled attention is required, and the expenditure on repairs is higher in the case of all internal combustion engines.

The Diesel oil engine is even more economical, and will consume practically any kind of liquid combustible, but for oil-field conditions it is somewhat expensive, and requires more attention than the ordinary Hornsby-Ackroyd variety. For permanent installations in well-sheltered buildings, under the immediate supervision of a qualified attendant, the Diesel engine is particularly applicable and exceptionally economical in fuel.

Gas Engines.—In the American oil-fields, gas engines have always been largely employed for power purposes other than for drilling, in consequence of the majority of wells in that country being pumped, thus permitting the simple provision of leading away the gas from the well by a side outlet pipe without any intermediary plant. In many of the eastern oil-fields of the United States, wells are specially sunk for gas which escapes under high pressure, and is either led direct or pumped to centres of commercial activity. Natural gas has a calorific value approaching 1,000 B.T.U. per cubic foot, compared with only 750 B.T.U. for artificial coal gas, but in practice the consumption per horse-power is about the same as coal gas, 9 to 15 cubic feet per horse-power

per hour according to the size of engine, &c. As natural gas usually contains moisture in suspension, and the pressure when the gas is led direct from the well often fluctuates, it is necessary to introduce a small gasometer for the equalisation of pressure and the separation of water when gas engines are supplied direct from oil or gas wells.

Gas engines are often operated by allowing the engine to draw its supply of gas direct from the well, the suction pipe being led into the well sufficiently below the surface to avoid the introduction of air during fluctuations of gas supply. If the engines are far removed from the wells from which they obtain their supplies, and there is either insufficient pressure to overcome the friction of pipes, or the wells are open to the atmosphere, as in the case of bailing or drilling wells, the gas may be extracted and forced to a distance by a small compressor, or, in the case of large volumes, by a fan or blower.

Most gas engines can be adjusted to utilise natural gas, although its variable composition and the fluctuating proportion of moisture introduce factors of uncertainty which sometimes cause erratic working for a time. Where the engines exceed 30 H.P. supplementary power should be provided for starting, as there is often far more trouble in starting than with an engine using gas of constant quality.

In new oil-fields where high gas pressures are met with in the wells gas is sometimes led direct to steam engines, and the engines run on gas instead of steam. The cooling effect of the expanding gas causes the condensation and freezing of moisture on the engine until often the machine becomes coated with a thick deposit of ice.

Electric Power.—Electric power has been introduced of late years into petroleum fields, but, curiously, least of all in the United States, where its adoption one would at first surmise would have proceeded most rapidly. One of the chief reasons for its unpopularity in America is the prevalence of the cable system of drilling, for which purpose

an electric motor is not so suitable as steam, owing to its lack of flexibility compared with that of a steam engine—which is almost universally employed for drilling—and the inability of instantly reversing the motor. Another reason for the disinclination to employ electric power in the United States is the comparatively short life of many fields, or rather the rapidity with which drilling operations are transferred from place to place, leaving the older fields comparatively deserted by operators, under which circumstances electric power stations of a permanent description would be thrown into disuse.

Electric energy has been introduced with success into the Russian and Roumanian oil-fields for both drilling and bailing, and under the usual oil-field conditions it has often proved more economical than steam power which it has generally displaced. Electric power can only be economically generated and successfully employed on a large scale, otherwise the "peak" loads thrown on at moments of unequal use become too severe. Polyphase, alternating, high tension current is usually generated for transmission to the centre of operations, where it is transformed into a lower tension service for distribution to the motors.

For supplying the oil-fields of Baku there are two large power stations with a collective capacity of about 16,500 H.P., the largest of which, at Whitetown, supplies the Balakhany-Saboontchy-Romany-Surakhany area, the smaller, at Baieloff, generating power for the Bibi-Eibat field. Both high speed vertical reciprocating steam engines and steam turbines are used for driving the generators which at Whitetown are three-phase alternators for a tension of 6,000 volts, and at Baieloff three-phase alternators of 2,000 volts, at which tension, in the latter field, the power is supplied direct to the motors. Part of the current from the Whitetown station is transformed up to 20,000 volts, at which tension it is conveyed to the outskirts of the field, where it is transformed to 1,000 volts for distribution.

The motors in general use on the Baku oil-fields for

drilling and bailing are of the enclosed type, developing at a speed of 700 to 750 revolutions a minute from 60 to 80 H.P. The average power consumed by boring wells is 6,000 to 6,500 kilowatts (8,000 to 8,700 H.P. hours) per month, and for bailing wells 11,500 kilowatts (15,500 H.P.) per month. When crude oil costs 20 copecks per pood (26s. per ton) the cost of power works out at 1¾ pence per kilowatt hour, equal to an average cost of about £85 a bailing well and £48 a boring well a month.

An electric power station was erected on the oil-fields of the South Pennsylvanian Oil Company at Folsom in West Virginia, where natural gas was burnt beneath water-tube boilers and vertical triple expansion engines were used for driving the generator. In this station were two three-phase alternators of 250 kilowatts running at 300 revolutions per minute with a voltage of 600. There was also one vertical type steam engine driving a 30-kilowatt multipolar generator suitable for exciting three alternators of 250 kilowatts each. Transformers were provided for transforming to 6,600 volts and 13,200 volts for long distance distributing mains, and at two 150-kilowatt stations situated respectively 2½ and 4½ miles away the current was transformed down to 650 volts before distribution to 10 H.P. motors. The motors were of the induction type, with two speeds in both directions, and governed by oil-break controllers. The plant was designed to pump about 200 wells, many of them intermittently, and the motors were also used for driving a small winch for raising the pump rods, &c. The mains were carried overhead.

Two large generating stations have been erected to supply electrical energy to the Roumanian oil-fields, where its use is rapidly extending.

At Sinaia four 250 H.P. Francis water turbines, utilising a head of 60 feet of water, drive four three-phase alternators of 3,000 volts. The current is transformed to 11,000 volts, and conveyed by overhead mains to the oil-fields, a distance of about 35 kilometers, with only a 5 per cent. loss. At the oil-

fields the current is transformed to 500 volts for power purposes connected with the wells and to 220 volts for lighting purposes.

At Campina there is also a generating station where three horizontal compound, tandem engines of 900 H.P. each and one compound vertical engine of 600 H.P. generate energy for the fields.

Electrical motors are usually erected in small fire-proof structures sufficiently near the derrick to allow a belt-drive to be arranged; and often a sliding door is arranged where the belt passes, which automatically falls or can be dropped if the derrick takes fire. In the Baku oil-fields the motor houses are built of brickwork or some other non-inflammable material, and the doors are made of iron.

The speed of the motor is reduced down by the introduction of a countershaft, on which pulleys of suitable diameter are keyed to take the belt-drive from the motor and transmit it to the boring machine, bailing drum, or pumping frame.

CHAPTER X.

THE COMBUSTION OF LIQUID FUEL.

Petroleum Fuel—Combustion of Liquid Fuel—Effect of Impurities on Calorific Value of Petroleum—Steam Atomisation—Air Atomisation —Gas Atomisation—Pressure Burners—Construction of Liquid Fuel Furnaces.

Petroleum Fuel.—The perfect combustion of petroleum cannot be accomplished without atomisation or pulverisation by some agent, during which operation the petroleum is not only sprayed in fine particles, but caused to become intimately mingled with air. To secure this essential condition some form of atomiser, sprayer, or burner, as it is variously termed, has to be provided, through the medium of which apparatus the petroleum is brought to the suitable degree of subdivision for complete combustion before ignition.

About the year 1865 several experimenters discovered that even heavy petroleums could be perfectly consumed by pulverisation with a jet of steam under high pressure before ignition, the kinetic energy of the steam inducing a fierce draught of air to encircle the flame whilst ejecting the oil in a fine spray. All modern oil burners are modifications and improvements of this original method of burning crude petroleum and residua, although the atomising agent is sometimes exchanged for air or other gaseous fluids.

Before the discovery of means for burning oils by the use of steam, immense quantities of heavy residual oils in the Baku oil-fields were annually burnt as the cheapest method of removing a nuisance, but since that date the residuals in Russia have generally dominated the petroleum market, owing to the immense demand which arose for this safe liquid fuel in the industrial district of the Volga.

The early worked fields of the United States yielded such a high grade quality of petroleum that the whole output was directed to more remunerative employment than that of liquid fuel, but since the development of the immense asphaltic petroleum deposits of California, Texas, and other States, the employment of liquid fuel has become very general in the Western States of America. The discovery of extensive oil-fields in the East Indies is leading to the increased adoption of liquid fuel throughout the East, whilst Roumania, Mexico, Peru, and Chili have long been large consumers of liquid fuel for railways and industrial factories.

Combustion of Liquid Fuel.—Crude petroleum varies in constitution, but for purposes of estimating its properties as a fuel, and calculating the products formed by its combustion, it may be taken to have an approximate composition by weight of 86 per cent. of carbon and 14 per cent. of hydrogen. As explained elsewhere the proportions of carbon and hydrogen vary somewhat in different oils, and there are often combined impurities, such as sulphur compounds, nitrogen, and oxygen, which affect the heating value, but these may be neglected in the general consideration of the combustion.

When a finely pulverised spray of petroleum is ignited in the presence of oxygen, or a plentiful supply of air, a fierce chemical action or oxidation is started, accompanied by intense heat and brilliant luminosity. The liquid hydrocarbons are dissociated and stable oxidation products are the ultimate result of imperfectly understood reactions which occur in the earlier stages of combustion. Whatever the character of the chemical actions which cause the gasification and dissociation of the constituents of the petroleum, the final result of complete combustion is always carbon dioxide and water diluted with free nitrogen, although there may be also produced through impurities, sulphur dioxide, &c., and as a result of imperfect combustion carbon monoxide and free carbon.

The chemical reactions are as follows:—

$$C + 2(2N_2 + O) = CO_2 + 4N_2$$
$$H_2 + (2N_2 + O) = H_2O + 2N_2.$$

The complete combustion of 1 lb. of hydrogen and carbon respectively yield the following results:—

1 lb. carbon requires 2.66 lbs. of oxygen to form 3.66 lbs. of CO_2.
1 lb. hydrogen requires 8.00 lbs. of oxygen to form 9.00 lbs. of H_2O.

The complete combustion of 1 lb. of petroleum of before-described composition, neglecting impurities, would result in the formation of the following products:—

0.86 lb. of carbon requires for complete combustion	2.29 lbs.	oxygen, producing	3.15 lbs. CO_2
0.14 lb. of hydrogen requires for complete combustion	1.12 lbs.	„ „	1.26 lbs. H_2O
1.00 lb. of petroleum requires for complete combustion	3.41 lbs.	„ „	4.4 lbs. gases

As the atmosphere contains 23.15 per cent. by weight of oxygen, the amount of free air needed to chemically combine with and complete the combustion of 1 lb. of petroleum is

$$\frac{3.41}{23.15} \times 100 = 14.75 \text{ lbs.},$$

or $14.75 \times 13.14 = 194$ cubic feet at normal temperature and pressure.

In practice an excess of air over that theoretically required is used, and the complete combustion of 1 lb. of petroleum of the composition already given will yield with a 50 per cent. excess of air the following products when a steam atomiser is used consuming 1 lb. of steam per lb. of oil:—

3.15 lbs. $= \frac{3.15}{.123} = 25.6$ cubic feet carbon dioxide (CO_2).
1.26 „ from combustion of oil }
1.00 „ used for atomisation } $= 58.7$ cubic feet steam.
11.34* „ $= \frac{11.34}{.0786} = 144$ cubic feet nitrogen (N).
7.38 „ $= 7.38 \times 13.14 = 97$ cubic feet excess air.

24.13 lbs. $= 325.3$ cubic feet flue gases.

* 14.75 lbs. of air, less 3.41 lbs. of O, used in the combustion of the fuel = balance of nitrogen.

In the above mixture there is by volume at normal temperature $\frac{25.6}{325.3} = 7.9$ per cent. of CO_2 and $\frac{58.7}{325.3} = 18$ per cent. of steam.

The complete oxidation of 1 lb. of carbon to carbon dioxide results in the evolution of 14,650 B.T.U., and the oxidation of 1 lb. of hydrogen to water causes the liberation of 62,100 B.T.U., consequently in the combustion of 1 lb. of petroleum the below-named heat in British thermal units is evolved if the above reactions take place.

$0.86 \times 14650 =$	12,600 B.T.U.	liberated from combustion of carbon		
$0.14 \times 62100 =$	8,694 B.T.U.	" " "		hydrogen
	21,294 B.T.U.	" " "		1 lb. petroleum.

The calorific value of a pure hydrocarbon can be calculated by the formula $x = 14,650\ C + 62,100\ H$.

The theoretical evaporative power of 1 lb. of crude petroleum of the above composition, and neglecting considerations of losses which will be considered later, is $\frac{21,294}{966} = 22$ lbs. of water from and at 212 deg. Fahr.

In practice the water formed by combustion traverses the furnace in a gaseous state, whereas in the above calculations the heat evolved in the formation of water in a liquid state is taken, so that this must be reduced by the latent heat of steam produced. Thus the effective heat resulting from the combustion of 1 lb. of hydrogen would be reduced by the latent heat of 9 lbs. of steam, or $9 \times 966 = 8694$ B.T.U., and become $62,100 - 8694 = 53,406$ B.T.U., consequently the calorific value of the fuel is reduced by $.14 \times 8694 = 1217$ B.T.U. or 5.7 per cent., and becomes 20,077 B.T.U. per lb.

The heat carried away by the gaseous products of combustion for each 1 deg. Fahr. of flue gases at chimney base is—

	Quantity.	Specific Heat.		
Carbon dioxide -	3.15 lbs.	× .216 =	.680	B.T.U. per 1 deg. Fahr.
Steam - -	2.26 "	× .479 =	1.083	" " "
Nitrogen - -	11.34 "	× .244 =	2.765	" " "
Air - - -	7.38 "	× .238 =	1.765	" " "

Total heat carried by gases = 6.293 B.T.U. per 1 deg. Fahr.

If therefore the flue gases have an escaping temperature of 600 degs. Fahr. the heat carried away is $(600-60) \times 6.293 =$ 3,400 B.T.U. per lb. of fuel burnt = approximately 17 per cent. of the heat value of an oil with a value of 20,000 B.T.U.'s per lb. In one case the author found the escaping gases at entrance to chimney from a battery of twelve boilers using oil, to have a temperature of 815 degs. Fahr., in which case the loss must have been approximately $\frac{(815^\circ - 60^\circ) \times 6.293}{20,000} = 23.7$ per cent. of the heat value of the fuel, if the oil had a calorific value of 20,000 B.T.U. per lb.

The complete combustion of petroleum can more easily be brought about than coal, although in the main points the same conditions must exist. A less surplus of air above that theoretically required is needed in the case of oil, although a too small air supply causes a far heavier cloud of smoke than does imperfect coal firing. A large combustion chamber is necessary, and oxidation should be complete before the heated gases leave the combustion chamber. Under normal conditions an excess of about 50 per cent. of air is sufficient, although care must be taken to assure the full oxidation of the carbon to carbon dioxide. There is a tendency to overrate the importance of the carbon dioxide in waste furnace gases, for the automatic measurement of which there are now so many appliances, but a too great reduction of air admissions may lead to a proportion of carbon monoxide through incomplete oxidation which causes far more loss of fuel than does an excess of air.

There are also other points of scientific interest connected with the combustion of petroleum which present problems of interest, such as the state in which the carbon is presented for union with oxygen. In the calculations given, carbon has been assumed to be present in a solid state, although it is known to exist in a liquid condition combined with hydrogen, therefore a certain amount of heat is rendered available which would otherwise have been absorbed in the

conversion of solid carbon into liquid; indeed, the excess of heat necessary to convert solid carbon into gaseous carbon over that necessary to convert liquid carbon into gaseous carbon, minus the amount required to dissociate the carbon and hydrogen is the balance of heat available. The carbon and hydrogen are presented in the first instance in complicated and numerous combinations which break down into other hydrocarbons when subjected to heat, so that it is impossible

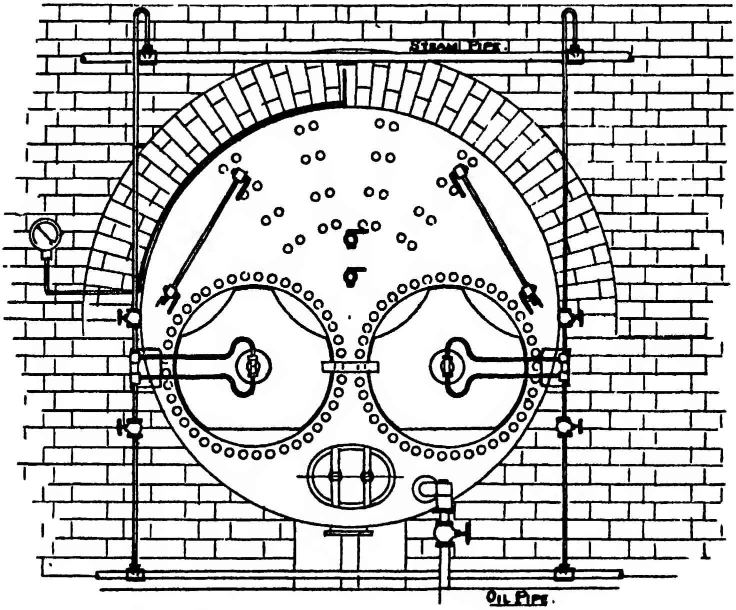

FIG. 110.—ARRANGEMENT OF LANCASHIRE BOILER FOR LIQUID FUEL WITH STEAM BURNERS.

to understand exactly what chemical actions take place in the furnace. Occasionally extraordinary evaporative results, such as 25 to 40 lbs. of water evaporated per lb. of oil, have been reported to have been obtained, and ingenious theories involving the dissociation of steam and the production of hydrocarbons with high calorific value have been submitted, but such results have never been confirmed, and were doubtless due to errors of observation or leakages of boiler fittings.

Water cannot be dissociated without the absorption of great heat, nearly 7,000 B.T.U. being absorbed in the dissociation of 1 lb. of water, which heat can only be abstracted from the flame. Steam is not and can never be a fuel such as some theories demand one to admit, although by the production of water gas by passage of steam through certain classes of bituminous coals improved combustion is said to be obtained.

The ultimate products of the complete combustion of petroleum are carbon dioxide and water, and as the actual calorific values of petroleum determined in calorimeters correspond very closely with the calculated figures based on simple chemical actions when due allowance is made for the presence of impurities, it may be assumed that the theoretical deductions are not far from correct.

The maximum normal evaporative result possible from a petroleum having a calorific value of 20,000 B.T.U. per lb., when completely burnt in a 50 per cent. excess of air, and escaping gases at 450 degs. Fahr. at chimney base, is about 16.25 lbs. of water from and at 212 degs. Fahr., equivalent to the conversion of 78.5 per cent. of the heat value of the fuel into steam. Evaporations have been recorded up to 18 lbs. from and at 212 degs. Fahr. on special experimental runs, but under normal commercial running with the best water-tube boilers not more than 16 lbs. can be obtained with a 20,000 B.T.U. per lb. fuel, whilst in less efficient Lancashire or Cornish boilers evaporation rarely exceeds 12 to 14 lbs. of water from and at 212 degs. Some of the Russian crude oils have a calorific value of about 22,000 B.T.U. per lb., when, of course, evaporative results exceeding those given could be reached.

The flame temperatures depend upon the manner in which the oil is burnt and the fluid used for atomisation. The theoretical temperatures produced by the complete oxidation of carbon and hydrogen when oxygen or air is employed are as follows:—

	In Air.	In Oxygen.
Temperature of flames when C burnt to CO_2	$=4,988°$ F.	$18,440°$ F.*
" " " H burnt to H_2O	$=4,554°$ F.	$12,202°$ F.

The furnace temperature may be approximately calculated from the examination of flue gases when the calorific value of the oil is known. By calculating the excess of air from the free oxygen in the flue gases, and estimating the specific heat of the flue gases from their composition, the initial furnace temperature can be deduced.

There is not the same necessity for high chimney draught with liquid fuel as with solid as the jet induces a draught itself, nevertheless it is important that the flues and chimneys be carefully designed to avoid unnecessary friction and to give free outlet to the atmosphere. A formula for chimneys that answers well in practice is $A=\frac{13F}{\sqrt{H}}$ where

$A=$ area of chimney in inches.
$F=$ lbs. of oil burnt per hour.
$H=$ height of chimney.

With a 100-foot chimney this is equal to an area of 1.3 square inches per lb. of burnt oil per hour, and it will give a chimney velocity of 25 to 30 feet per second under normal conditions of combustion.

Effect of Impurities on Calorific Value of Petroleum.—The most common adulterant in petroleum is water, either in simple suspension or as an emulsion. The extraction of even suspended water in a heavy crude or residuum oil is sometimes a difficult operation, and can only be accomplished by heating the oil and so reducing its specific gravity. Texas and Californian crude fuel oils of .920 specific gravity or more present considerable difficulties in the elimination of water, and the author has found 2 to 3 per cent. of suspended water in both Texas and Californian oil after prolonged

* Booth's "Liquid Fuel and its Combustion."

settlement in tanks and transportation over several thousand miles. The simplest way of detecting and estimating suspended water is to mix the petroleum with an equal amount of benzine, when the separated water may be measured after an interval of several hours.

Emulsified water is much more difficult to detect or estimate, although a chemical analysis can always be made. Long settlement or heating in tanks will cause the separation of water from some emulsions, but often no separation can be effected by simple means, and the oil will have to be burnt mixed with the water. With air atomisation the author has burnt oils containing as much as 30 per cent. of emulsified water, but naturally the heat value is greatly reduced. Crude petroleum raised by the air-lift process from wells in which there is water sometimes yields an objectionable emulsion, and at gas works where water-gas plants are in operation emulsified water-gas tar often defies the efforts of the management for a while.

The presence of water in petroleum fuel naturally has a very serious effect upon its calorific value, for not only does the water replace the equivalent volume of combustible matter, but it has to be converted into steam and raised to a high temperature, when it acts as a diluent of the flue gases and carries away heat. Mr Orde, in a paper to the Institute of Mechanical Engineers in July 1902, called especial attention to the injurious effect of contamination of petroleum with water, which he asserted, amongst other objections, not only reduces the total value of the fuel but destroys the essential conditions for perfect combustion. Professor Vivian Lewes has also called attention to the great losses sustained by the admixture of a little water with petroleum, and advises the alternate heating and cooling of the oil in settling chambers until separation is effected. The reduction in the calorific value of a sample of oil containing 5 per cent. of water is about 1,100 B.T.U. per lb., equivalent to an evaporation of over 1 lb. of water.

Other impurities which are sometimes present in petroleum are oxygen, sulphur, and nitrogen. Oxygen combines with hydrogen in the fuel directly combustion is started, forming water, and consequently robs some of the hydrogen of its fuel value. The proportion of oxygen in petroleum is always small, although in solid fuels it often amounts to 7 per cent. The presence of oxygen in a fuel modifies the calculation of calorific value (x) as follows:—

$$x = 14{,}500\,C + 62{,}100\left(H - \frac{O}{8}\right)$$

where x = calorific value in B.T.U., C = weight carbon, H = weight of hydrogen, and O = weight of oxygen in 1 lb. fuel. Sulphur when present unites with oxygen forming sulphur dioxide which eventually is converted into sulphuric acid by combination with water. Nitrogen takes the form of an inactive diluent only, and its presence simply causes a reduction in calorific value equivalent to the amount of petroleum it replaces, whilst neither supporting nor retarding combustion.

Steam Atomisation.—The atomisation of liquid fuels is most commonly effected by a jet or series of jets of steam. Quite distinct from its undoubted convenience as an atomising agent in a boiler, steam is a more efficient material for the purpose than would be supposed on first considerations. Until recently steam pulverisation has been almost universally adopted since the first employment of liquid fuel, but during recent years mechanical spraying has been successfully and economically introduced, and air systems have become increasingly popular for special purposes. One of the main objections to steam is that other means are necessary to raise pressure before there is sufficient steam to work the burners, unless there are other boilers under steam near by. Boilers under such circumstances are either fired for a while with coal or wood, or the atomisation is accomplished by air compressed by hand, or some other source of energy.

Intimate contact between the petroleum and steam leads to complete combustion on ignition through several causes. The kinetic energy of the expanding steam disperses the oil in a fine spray, the lighter fractions of some oils being at the same time converted into gas, whilst in addition a strong draught of air is induced towards the jet, and so oxygen is provided for the oxidation of the constituents of the fuel. As steam only causes the necessary admixture for combustion and plays no part in the chemical reactions which occur in the furnace, it is desirable to limit the quantity as much as possible. All steam admitted is raised to the furnace temperature, and in its passage to the atmosphere carries with it both latent heat and that due to its temperature, without performing any useful purpose, except, perhaps, that which is sometimes claimed of reducing the fire-box temperature to a less dangerous degree than when steam is not used. Saturated steam used for pulverising should be free from water, and it is preferable to superheat the steam before admission to the burners, the degree of superheating being regulated to suit the particular oil used. High superheating will cause the conversion of a part of the oil to gas, but sometimes it will also lead to a deposition of carbon from some oils, which consequently choke the burner.

The quantity of steam required for atomisation varies with different burners and with different kinds of fuel, the heavier Californian crude oils and Russian astatki requiring more steam than light Russian or Peruvian crude oils. From 5 to 10 per cent. of the steam generated covers the usual practice, although sometimes the amount of steam in ill-designed plants will be as much as 12 to 14 per cent. The most efficient pressure of steam also depends upon the design of burner, although they are usually worked at pressures from 30 to 60 lbs. per square inch. Perfect atomisation and complete combustion can be established by careful adjustment in a well-designed burner with the consumption of $\frac{3}{4}$ to 1 lb. of steam per lb. of petroleum.

Steam accompanied by much water will extinguish the flame, and even a little moisture in the steam used for spraying will prevent perfect combustion and lead to a red smoky flame amidst which clouds of dirty grey steam will be visible.

Air Atomisation.—The objections to steam pulverisation have always been recognised by engineers, but its simplicity has always recommended its preference to air when independent machinery has to be provided for compressing. Air supports combustion whilst steam does not, so that by air atomisation a much higher initial furnace temperature is obtained. Steam causes a longer flame, due to delayed combustion, than does air where combustion is almost immediate. It is undoubtedly an advantage to have the highest furnace temperature possible, as not only do the hottest gases have a longer distance over which to impart their heat to the boiler, but there is less liability of the condensation of partially consumed hydrocarbons on coming into contact with the cool surfaces of the boiler tubes. It is always desirable to effect complete combustion in the fire-box surrounded by heated firebrick, and only allow the perfectly oxidised products to come into contact with the cooler boiler surfaces. With steam, combustion is sometimes delayed so much that this condition does not exist, and cooled unconsumed hydrocarbons escape as smoke into the atmosphere.

Slight variations in the proportions of air and petroleum do not affect the combustion to the same extent as with steam. A slight increase or decrease in the flow of oil through the filling or emptying of the fuel tanks will cause a whole row of boilers with steam atomisation to smoke, and likewise a small variation of steam pressure will cause a similar result. Many engineers object to air as an atomising agent on the ground that the intense initial temperature causes damage to the boiler. That greater precautions must be taken to prevent unequal heating in the fire-box, and that a direct impingement on the fire-box must be avoided, there

is no disputing, but a skilfully designed firebrick fire-box should prevent boiler damage. By a direct short impingement of an air burner in some tests at a London glass works it was possible to melt the finest Stourbridge crucible fire-brick, such as is used for crucibles for melting hard glass, thus indicating the high flame temperature accompanying air atomisation.

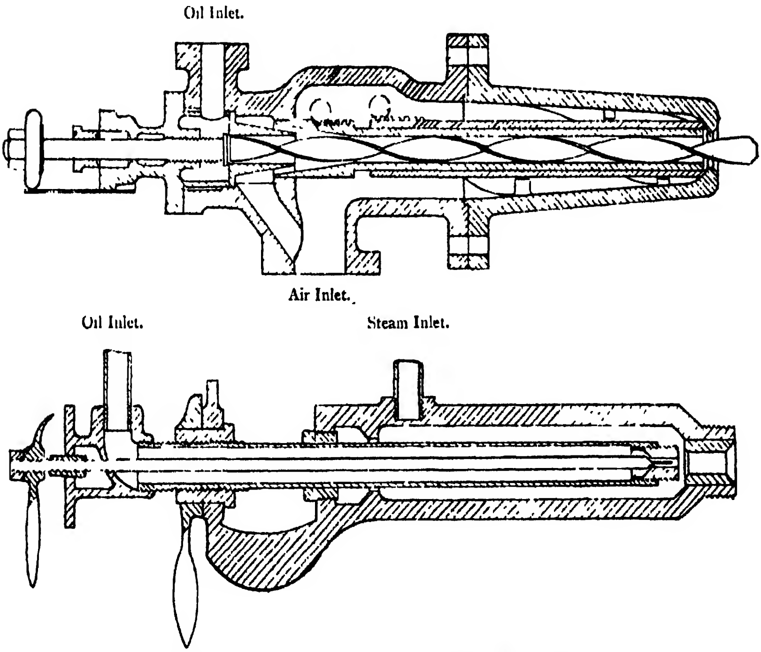

FIG. 111.—KERMODE AIR BURNER AND KIRKWOOD STEAM BURNER.

Air used for pulverising may with advantage be heated to between 500 and 600 deg. Fahr. before admission to the burners, partial vaporisation of some oils being thereby effected and consequently quicker and more perfect combustion resulting. The majority of air burners will not bring about perfect atomisation under an air pressure of 30 to 60 lbs. per square inch, which naturally necessitates the expenditure of considerable power in compressing the air. A common atomiser applicable for steam at 60 lbs. pressure

will need, when used with air, a consumption of from 2 to 3 lbs. of air at about the same pressure even when heated.

The practical utilisation of the kinetic energy of escaping steam is apparent when comparing steam and air consumption, for 26 to 39 cubic feet (2 to 3 lbs.) of air will only perform the same duty as 19.5 to 26 cubic feet ($\frac{3}{4}$ to 1 lb.) of steam, although the former is a supporter and the latter a non-supporter of combustion. Under such circumstances air pulverisation would cost in steam consumption about twice as much as direct steam pulverisation, *i.e.*, pulverisation by air compressed to 60 lbs. pressure in a compressor, with a consumption of 40 lbs. of steam per B.H.P., would take about 1.6 lbs. of steam per lb. of fuel burnt, compared with a consumption of .75 lbs. of steam with steam pulverisation. Unless, therefore, considerably increased evaporative efficiency follows the employment of air burners under the above conditions, the cost would be much higher in the case of air when interest, depreciation, and upkeep of subsidiary plant is considered.

There are now, however, air burners which will produce complete atomisation with air at 3 lbs. pressure, and although some 3 to 4 lbs. of air per lb. of fuel are needed, the power for compressing is much reduced. With low pressure air burners perfect combustion can be easily accomplished with a consumption of less than $\frac{1}{2}$ lb. steam for the air compression per lb. of oil, taking as before 40 lbs. of steam per horse-power per hour. Manufacturers of low pressure air burners claim that they can reach a 10 to 20 per cent. higher evaporative efficiency than with steam burners, although the higher amount cannot obviously be obtained in cases where direct tests with steam burners have shown an evaporative efficiency of 75 per cent. of the heat value of the fuel. Under normal conditions of working with unskilled labour, it is certain that air pulverisation gives better all-round results, as imperfect adjustment of the proportions of air and oil do not so adversely influence the combustion as is the case with steam burners.

If a reciprocating compressor is employed for air compression, a large receiver or accumulator must be placed near the outlet to equalise the pressure, or the burners will pulsate. Rotary blowers, or Turbo-blowers are preferable on account of the constant flow of air they discharge.

Air burners will consume almost any class of liquid combustible, such as gas tar and precipitated refinery tars, even if heavily contaminated with water. In 1905 to 1906 the author's firm directed the erection of an installation of air burners for glass furnaces, using as fuel water-gas tar, the refuse of water-gas plants at gas works. The waste tar from Mond gas plants, and the deposit of refining in oil works, have also been used as fuel.

Gas Atomisation.—A somewhat novel method of pulverisation was elaborated by Mr Campbell M. Hunter and the author in 1907, whereby natural gas was used for the purpose instead of air or steam. The scheme was prepared for an oil property where there was insufficient gas to utilise direct in a large number of boilers where steam oil burners were in use, and the object was to save most of the 10 per cent. of fuel lost by steam pulverising, by using instead natural gas drawn from the wells and forced under pressure to the burners. Not only is there the saving of steam, as the quantity needed for compression is much less than 10 per cent., but a combustible of a high calorific value is added to the oil and caused to perform the duty of pulverising, and the combustion is not impaired by admixture with a non-combustible.

Pressure Burners.—For several years attempts have been made to introduce a burner which would itself disperse the oil in so fine a spray that no extraneous agent would be needed, thereby avoiding the necessity of directly using either steam or compressed air in the furnace. The loss of steam in pulverising is often a serious matter, particularly

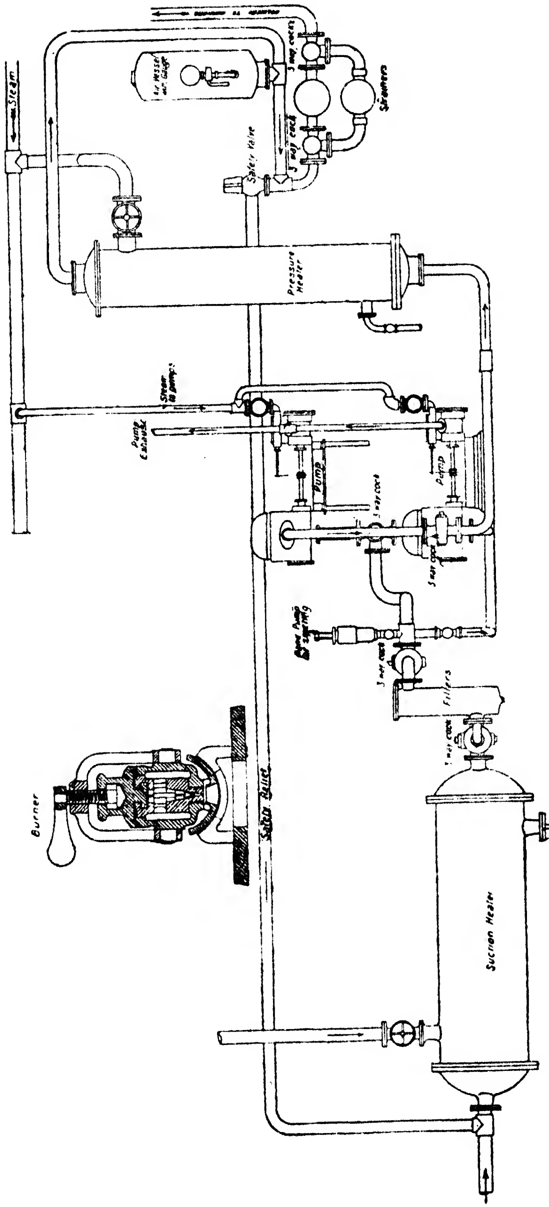

FIG. 112.—SHOWING GENERAL ARRANGEMENT OF ACCESSORIES FOR A PRESSURE BURNER INSTALLATION.

on board ships, where it has to be made good by evaporators, and although by the use of air burners the loss is removed by allowing the engine driving the compressor to exhaust into the condenser, the power consumed by all but a few types of low pressure air burners is considerable. Korting's burner was the first pressure burner to receive anything approaching general recognition, and in this the oil was pumped under high pressure to an ejector which dispersed the oil in such a fine spray that ignition was almost as instantaneous as with a steam atomiser.

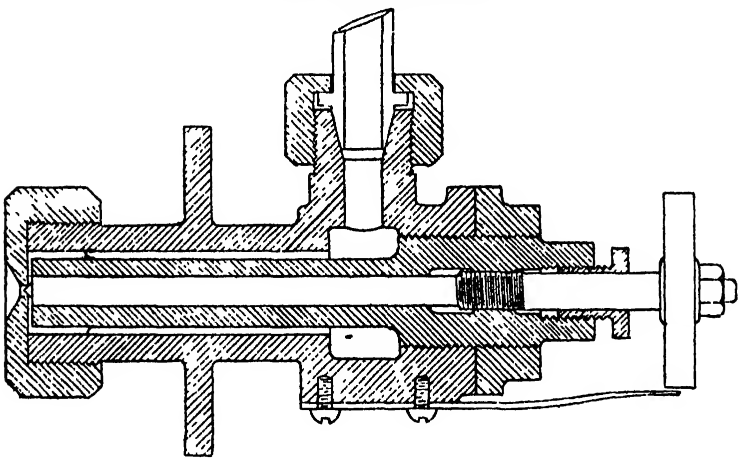

FIG. 113.—KERMODE PRESSURE BURNER.

There were several important difficulties which had to be overcome before the pressure burner could be called a commercial success, perhaps the most important being the plugging of the fine orifices, which naturally constitute a main feature of such burners, as it was found that the least particle of grit or foreign substance was sufficient to choke the burner. This was overcome by passing the oil on its passage to the burner through a succession of filters where absolute freedom of suspended matter was assured, and usually this process was assisted and the fluidity of the oil increased by heating the

oil with a steam coil. In all pressure burners, combustion must be aided by heating the oil to a high temperature before admission to the furnace, and by using a forced draught, and these constitute an inevitable accompaniment of present-day pressure burners.

Korting's pressure burner illustrated in Fig. 112, relies upon the expulsion of oil through minute circular holes under high pressure to produce the necessary fineness of spray. The same result is achieved in Thornycroft's burner by an ingenious form of conical nozzle by which the oil is expelled tangentically against a face which in turn converts the oil into a rotary motion and a fine spray. In Kermode's pressure burner (Fig. 113) the spraying is effected by the rebound of the oil on two conical surfaces correctly placed to cause this.

Construction of Liquid Fuel Furnaces.—The exceedingly high furnace temperature resulting from the combustion of liquid fuel renders it necessary to protect the plates of the firebox with some refractory material, and for that purpose it is usual to line the combustion chamber with firebrick where the fiercest temperature occurs. The secret of perfect combustion depends upon sufficient space being allowed for this to take place in the combustion chamber before the products reach the comparatively cool surfaces of the tubes, otherwise a condensation of unconsumed hydrocarbons takes place and smoke ensues. In attempts to adapt coal-burning boilers to oil this main requirement of combustion space is often overlooked, with the result that expectations are not realised, as the cubic capacity which should have been increased has actually been diminished by the insertion of a firebrick lining. The ordinary Colonial type of boiler, with specially large firebox made for burning timber, can always be readily adapted to liquid fuel, but in other types it is advisable to enlarge the firebox where possible, either by building a firebrick chamber beneath the grate or in some other way that the design suggests.

It is usual to direct the flame beneath a firebrick arch, over which the heated gases pass before they come into contact with the unprotected portion of the plates, and it is good practice to allow at least 1 cubic foot of furnace space for each 10 lbs. of oil burnt per hour. Where ordinary Lancashire or Cornish boilers are converted to oil the limited space of the furnace tubes does not admit of reduction of area by a firebrick lining, and in such cases the burner may be directed horizontally along the furnace tubes without directly impinging upon any plates. This practice, though common, is not good, although the combustion is better than would be thought owing apparently to the formation of a layer of air between the flame and the boiler plates which prevents direct contact of the imperfectly consumed gases with the plates.

An oil fuel furnace should be so arranged that the air supply can be regulated to avoid an excess which will unduly lower the temperature of the furnace. The injector action creates a draught around the burner, and this supply should be capable of adjustment by a rotating slitted door, which can be fixed in any desired position to admit a fixed quantity of air. Approximately 60 square inches of air opening should be allowed per 10 gallons of oil burnt per hour. The proper adjustment of air admission can be made by inspecting the flame through a sight hole, when the flame should be short, bright, and clear.

In the construction of liquid fuel combustion chambers and arches only the best quality firebrick should be allowed, and it is desirable to use the specially constructed bricks with locking strips, otherwise the arches often fall in after a little use. The exposed nuts of stays in a firebox, where unprotected by the brick lining, are often covered by fireclay caps, which can be purchased.

CHAPTER XI.

THE MEASUREMENT, COLLECTION, TRANSMISSION, AND UTILISATION OF NATURAL GAS.

Natural Gas—Collection of Natural Gas—Measurement of Flow of Gas—Combustion of Natural Gas.

Natural Gas.—The conditions under which natural gas occurs in nature, and the phenomena associated with its distribution, have been fully described in the preceding chapters.

Analyses and calorific values of natural gases from widely separated oil-fields have been given in Chapter IV., and some idea of the waste of this valuable fuel can be gleaned from the figures on p. 90.

Enormous use is made of natural gas in the United States, and around Pittsburg most of the great iron and glass works extensively employ gas which is often obtainable at 10 cents (5 pence) per 1,000 cubic feet. Some of the gas mains leading to Pittsburg have a diameter of about 36 inches, and a daily capacity of over 100,000,000 cubic feet. The pressure in the mains from the gas-fields is often several hundred pounds per square inch, but it is reduced to about 4 ozs. (of water) in the city distributing mains.

In the Canadian gas-fields the gas is likewise led, under a pressure of 200 lbs. per square inch or thereabouts, to the centres of consumption, where it is distributed at a pressure of from 2 to 6 ozs. per square inch to the consumers. In the city of Chatham in 1907 the charges for natural gas were as follows :—

Lighting and cooking	-	35 cents per 1,000 cubic feet.
Heating up to 100,000 cubic feet	-	27 " " "
Heating from 100,000 to 150,000 cubic feet	-	22 " " "
Heating above 150,000 cubic feet	-	17 " " "
Gas engines	-	15 " " "
Firing boilers	-	12 " " "

Natural gas, comparatively free from nitrogen and carbon dioxide, may be considered to have a calorific value of about 1,000 B.T.U. per cubic foot, from which it can be deduced that from 19 to 20 cubic feet of gas are equivalent in heating value to 1 lb. of crude oil, or 42,500 to 45,000 cubic feet per ton.

In practice, however, it is found that a larger margin must be allowed, and in the Baku oil-fields, where the theoretical heating equivalent of 1 pood (36 lbs.) of crude oil is 728 cubic feet in natural gas, it is found that about 770 cubic feet are consumed under the boilers to replace this amount of crude.

The air needed for combustion can be calculated from the composition of the gas in the same way as oil (see p. 321), the ultimate products of complete combustion being carbon dioxide and steam, as with oil.

Methane is usually the predominating hydrocarbon in oil-field gases all over the world, but sometimes there is also a proportion of other hydrocarbons present. A quantity of extremely light spirit condenses from the gas issuing from some wells, and collects in the mains from whence it must be periodically abstracted at a depressed point, or in a trap placed for its reception.

A test of one sample of such spirit showed a specific gravity of 0.755 at 60 Fahr.

A natural gas of ordinary composition only becomes explosive when it is mixed in the proportion of from 6 to 12

per cent. with air, the critical percentage and most explosive point being reached with a mixture of 9.6 per cent. methane with air.

Such a diluted mixture of gas could never be approached in usual oil-field operations where ordinary precautions were adopted, but nevertheless the simple precaution of arranging a water-seal outside boiler-houses and points of consumption should never be omitted, where there is the possibility of air gaining access to the gas mains.

In those cases where exhausters are in use, and there is the possibility of air being drawn into the mains in large quantities, the additional precaution of a wire gauze near the mouth of the burner should be taken, a back fire into the mains being thereby impossible unless the gauze became overheated or an explosion occurred in the furnace chamber of the boiler when lighting up, which would cause the flame to leap past the gauze.

The proportion of air and gas cannot readily be ascertained nor can the proportions be automatically registered, and the composition of the mixture in the gas mains can only be determined by a test in an Orsat apparatus, or some suchlike appliance.

Collection of Natural Gas.—When wells are sunk exclusively for gas and no petroleum exists, the gas, when registering a high pressure, is usually conducted direct into mains which lead either to centres of industry or to large compressors where it is forced under still higher pressure to industrial points. When the pressure has decreased and the output of gas has considerably diminished, an increased yield is obtained by drawing the gas from the wells and in many cases maintaining at the mouth of the well a partial vacuum.

In the great Appalachian gas-fields which have contributed so largely to the prosperity of Pennsylvania, the diminishing volumes of gas and smaller pressures registered as a result of gradual exhaustion have led to the installation of enormous

gear-driven exhausters and compressors for impelling the gas under high pressure to areas of consumption such as Pittsburg and Cleveland.

Increased attention is now being displayed towards the employment of natural gas issuing from oil wells, where till recently few attempts had been made to preserve and utilise this valuable source of energy in the important oil-fields of the world.

In the collection of natural gas several important points must be considered when the outflow of a number of wells are led under natural earth pressure to a single main, otherwise considerable losses may result. Whilst the closed pressures of two or more wells after an interval of rest for the establishment of equilibrium may coincide, the open pressures of the same wells may vary considerably on account of different subterranean conditions which retard or favour the movement of gases. The pressure in an open main is fixed by the resistance, and if the flow of gas is such as to raise the pressure in the main above the natural earth pressure of one or several of the wells, gas will flow from the high pressure wells to those indicating a low earth pressure, the total yield being diminished instead of augmented by the connection of such wells. This phenomenon has been demonstrated by the author by actually testing individual wells, and then ascertaining the combined flow when coupled up, the results being the reverse of those anticipated on account of the absorption of gas from the higher pressure wells by the lower.

A back flow of gas may be prevented by attaching a check valve at each well where the supply is in excess of demand in order to seal up paths of possible loss, but if the whole available supply of gas is needed the mains must be sufficiently large to avoid a pressure exceeding that of the lowest well pressure, when no check valves will be needed. Where the pressures are very low, a partial vacuum is often maintained in the mains by an exhauster, thus assuring the maximum yield of gas from any group of wells.

Collection of Gas from Pumping Wells.—Where wells are operated by means of the deep well pump the collection of gas is a simple matter, as it is led away from the side outlets on the casing head at the mouth of the well to points of consumption, or drawn from thence by exhausters.

Where the wells are widely separated and the issuing gas is required at a distance, a usual practice is to instal a small vertical reciprocating gas pump near the mouth of the well, operated by a rod coupled to the walking beam. By adjusting the position of the gas pump, any desired stroke can be arranged according to the volume of gas yielded by the well.

A large amount of gas always escapes with the oil in pumping wells, and where great economy of fuel is exercised it is a practice to fix gas tanks at each well into which the discharge pipe of the oil pump flows.

Gas tanks are simply constructed and consist of cylindrical iron drums, into the top of which is conducted the discharge pipe of the pump and from which a gaspipe emerges. The oil, from which the gas separates while discharging into the tank, collects to a certain height in the tank before its outflow commences, and the level of oil is automatically maintained at a fixed point above the exit pipe by a float, syphon, or some other device which controls the discharge cock.

Where the variations in pressure are not great, a gooseneck connection at the bottom of the tank for the oil outflow is sufficient to create a seal and prevent the escape of gas, but if the well is liable to "blow," this method, of course, could not be adopted, as the pressure of gas would probably exceed the liquid "head" of the gooseneck, and the oil and gas would be blown out of the tank.

Wells which make periodical flows from the pump tubes whilst being pumped often yield great volumes of gas, which may be recovered by the aid of gas tanks fixed in the manner indicated.

The yield of gas from pumping wells varies greatly. New wells may yield from 40,000 to 1,000,000 cubic feet per day,

whilst old wells or those sunk in less prolific fields may only yield from 5,000 to 20,000 cubic feet daily.

Collection of Gas from Bailing Wells.—The collection of gas from oil wells which are being bailed, and consequently have a free outlet at the surface to the atmosphere, is not such a simple operation as with pumping wells, but, nevertheless, it can be performed if suitable provision is made for sucking the gas away. To ensure comparative freedom from air, the gas must be drawn from bailing wells some distance from the surface, as the alternate ascent and descent of the bailer in the well and the agitation suffered by the liquid encourages the irregular liberation of the gas, making it necessary to allow sufficient "cubic" above the gas intake to compensate for these fluctuations.

In completed wells, where no suitable preparation for the collection of gas can be made, a tube is inserted through the casings as far beneath the surface as possible, and then led to an exhauster which draws away the gas; but a better plan is to perforate the last string of casing at a depth of 100 to 200 feet below the surface, so that the gas can enter the space between the casings and be drawn from thence by some form of exhauster. If the annular space between the casings is sealed at the surface, air could only be admitted by being drawn down the central casing of the well from the surface.

As bailing wells invariably exhibit a widely fluctuating yield of gas, it is necessary to provide a cock or valve on the suction pipe for adjusting the area of the intake, and it is further advisable to have an indicator to show if air is being drawn in from the surface. A simple method is to direct a minute jet of steam over the mouth of the well, when the direction of the flow of gas can be instantly observed at any moment by the deflection of the steam.

If it is important to collect gas without any admixture of air, the intake must be so adjusted that some gas always

issues from the mouth of the well, but as there is no objection to a small proportion of air for many purposes, the cock can be so adjusted that a little air is drawn in also, reducing thereby the loss of gas to a minimum.

The collection of gas from a group of bailing wells not far separated from each other can most economically be effected by having a common suction main of ample dimensions into which the various intakes are led from each well. A partial vacuum is maintained in the suction main by some form of exhauster, the character of which depends upon the volume of gas to be dealt with and the pressure needed on the delivery side. For large volumes of gas with a delivery pressure of only a few inches of water a fan or blower is best adapted, but for smaller volumes of gas and a higher delivery pressure a Roots blower or reciprocating compressor is preferable. Where large volumes of gas have to be forced to pressures of several pounds per square inch a turbo-blower is the best form of exhauster to employ.

In the design of a large installation by Thompson & Hunter to deal with 1,000,000 cubic feet of gas daily, arrangements were made for drawing the gas from the wells by means of an exhaust steam turbine direct, coupled to a turbo-blower, through a main encircling the oil property, and delivering under 7 lbs. pressure to a battery of boilers. The maintenance of a constant vacuum was assured automatically by a device by which any rise in the vacuum controlled the steam regulator.

Small turbo-driven fans may with advantage be placed at isolated wells for dealing with low pressures, but usually for the extraction of gas from widely separated wells and its transmission to points of use, a small reciprocating compressor, driven by belting from a countershaft or some part of the machinery, may be used with advantage.

Wells in the Baku and Grosny oil-fields of Russia, where bailing is chiefly practised, give widely fluctuating volumes of gas, but an average of the yield of old and new wells would

probably not be far short of 30,000 cubic feet daily. New wells often yield not less than 500,000 cubic feet daily, but wells which have settled down to a normal state give usually from 30,000 to 60,000 cubic feet daily.

The Collection of Gas from Air-Lift Wells.—The gas escaping from air-lift wells can be conveniently collected in the same way as from wells pumped by a deep-well pump, but it is necessary to ascertain that the gas so collected is not mingled to a dangerous degree with air which, especially in the case of intermittent action, often finds admission into the well.

Air-lift discharges vary considerably in composition, according to the volume of air used and the character of the oils raised, but a highly inflammable mixture is nearly always generated as a consequence of the intimate association and agitation of the two fluids. Besides the normal gases which always issue from oil when freshly drawn from subterranean sources, a proportion of other hydrocarbons are liberated as a result of the fierce agitation which proceeds in the air-column, and a richly carburetted air mixture often results.

In oil-fields where the oils are light the carburetted mixture from air-lift plants may be led direct to the boiler furnaces after being directed through a tank where the oil can separate, but there is considerable danger that moments may exist when the proportions of air and gas reach an explosive limit, and great damage may result.

In one case the author had brought to his notice an explosion which originated in this way and caused considerable damage, although the system had been in successful operation for several months without an accident, no one having apparently realised the danger that existed, as no water seal had even been interposed in the delivery gas main.

Carburetted air can more safely be used by admitting the mixture to large mains conveying pure gas in considerable

quantities, the percentage of air never then approaching dangerous proportions.

Unless the output for air-lift wells is intelligently directed to use, there are great risks of an explosion, and no attempts should be made in that direction without skilled advice.

Measurement of Flow of Gas.—The yield of gas wells can be measured by ascertaining the pressure at which the gas issues through a circular orifice of known area and calculating the velocity therefrom. When high gas pressures are registered in an open tube, an ordinary pressure gauge may be attached to a length of bent tubing, the open end of which can be held vertically over the mouth of the well; but for low pressures an ordinary U tube or water gauge can be applied in the same way, and the pressure read off in inches of water or other fluid inserted in the U tube.

In general practice a modified form of water gauge is often used, known as the Pitot gauge, tube, or instrument, which is not only applicable to gas yields from open orifices, but also for ascertaining the velocity of gas in mains.

The Pitot tube is an instrument for determining the velocity of a current of liquid or gas flowing either in an enclosed tube or open duct, or discharging into the atmosphere.

It is composed of a bent tube with an orifice directly opposing the direction of flow, and also a side orifice to equalise any difference of pressure due to static head.

It is attached by a piece of flexible tubing to a U gauge or other type of pressure gauge, and there registers the difference of pressure due to velocity head.

The liquid used in the U gauge may be either water, kerosene, alcohol, or mercury, according to the amount of pressure to be measured, or in the usual spiral of a Bourdon pressure gauge for high pressures above, say, one atmosphere, when the dimensions of a U gauge with mercury would become inconveniently large.

The calculations for the measurement of gas flowing from an open orifice, such as the mouth of a well casing, can be expressed as follows:—

If h inches represent the height of a column of gas of specific gravity s (air = 1), equivalent to a displacement h^1 inches of liquid of specific gravity s^1 in the legs of the U gauge.

Then $hws = h^1w^1s^1$ or $h = \frac{w^1}{w} \times \frac{s^1}{s} \times h^1$ inches, where w is the weight of 1 cubic foot of air, and w^1 that of 1 cubic foot of water.

Assuming the truth of the formula for the velocity of a liquid issuing from an orifice due to head h, $v^2 = 2gh$, and inserting the value of h found above, we get the velocity

$v = \sqrt{2g\frac{w^1}{w} \times \frac{s^1}{s} \times \frac{h^1}{12}}$ feet per second.

Careful experiments have been made for testing the truth of this formula applied to the practically frictionless orifice of a Pitot tube, and it has been proved correct.

Having obtained the velocity, all that is required is to multiply it by the cross-sectional area of the pipe in square feet to obtain the volumetric discharge in cubic feet per second.

There are some practical considerations in the use of the Pitot tube which must be attended to in order to obtain reliable and consistent results.

First, the mouth of the opening to which the tube is applied must be even, so as to avoid creating eddy currents due to uneven area of discharge, and for this purpose the length of the portion of the pipe to twenty times its diameter should be free from bends, joints, T pieces, and other connections which tend to create eddy currents, that is to say, the pipe should be smooth, and its mouth should be free from burrs.

Secondly, should the area of the pipe be large for the quantity of gas passing, so as to prevent a reading of a

velocity pressure, it should be reduced until a convenient size has been reached to give an accurate reading.

Thirdly, measurements of flow taken at atmospheric pressure must be free from "adiabatic" flow in the tube, whereby the pressure at the mouth of the tube is considerably above atmosphere. The tube should be placed at the mouth of the orifice, and not in it nor away from it. Readings on the U gauge are generally small, and it is convenient to use kerosene as the liquid, as it is lighter than water and offers less resistance to friction on the sides of the glass.

The measured quantities should be increased by a suitable percentage to allow for air before proceeding to calculate sizes of mains.

Having determined approximately the daily output of gas from the group of wells, calculations must be made for selecting the proper diameter of suction main. The loss in friction for air or gas along a wrought-iron pipe can be taken at 1 velocity head per every 32 diameters of pipe, the velocity head h being equivalent to $\frac{v^2}{2g}$. Thus the friction loss in a pipe l feet long and d inches in diameter is $\frac{l}{32} \times \frac{12}{d} \times h \times s$, where s is the specific gravity of the gas (air = 1).

To reduce this to inches of water pressure it is necessary to divide by 68, since 68 feet represents the column of air at atmospheric pressure and 60 deg. Fahr. corresponding to one inch of water pressure and we get the friction loss

$$\frac{l}{32} \times \frac{12}{d} \times \frac{v^2}{2g} \times \frac{s}{68} \text{ inches of water.}$$

The maximum suction to be maintained in the main to overcome friction, as calculated above, should be increased by a few inches of water to create flow at the well.

Such calculations as the above are useful in deciding one upon the type of machine to employ. Exhausters cannot maintain a very high suction, but can handle large volumes

delivering at low pressure. Reciprocating pumps and compressors maintain a very high vacuum on the suction side which increases the velocity of flow but requires greater power. This higher vacuum renders the use of large suction pipes less necessary, but often on oil properties there are to be found many lengths of old or damaged casing of large size, which may very well be used for gas suction mains, so that the cost of outlay in piping does not enter into account to such a degree, and it is then a problem of economising in power for the compressor or exhauster. The frictional resistance in the discharge main of an exhauster or compressor is generally provided for by the formula

$$d = \sqrt[5]{\frac{Q^2 l}{p}} \times 0.07,$$

where d is the diameter of the main in inches, Q the cubic feet of gas per hour passing, l the length of main in yards, and p the pressure in the main in inches of water.

Table XL. shows the flow of gas in cubic feet a day from pipes of various diameters between 1 inch and 6 inches diameter under different pressures. The volume of gas is calculated at 32 deg. Fahr., and the specific gravity is taken at 0.6, air being unity. Corrections for other densities or temperatures of gas can be made as indicated.

The yield of gas wells can be approximately estimated from the capacity of the borehole in cubic feet, and noting the increase in pressure in one minute after the outflow is closed.

$$Q = \frac{d^2 \times 3.1416 \times L}{4 \times 144} \times \frac{p}{15} \times 60 \quad \text{or} \quad Q = \frac{1}{48} d^2 L p.$$

Q = cubic feet of gas per hour into atmosphere.
d = diameter of well in inches.
L = depth of well in feet.
p = pressure in lbs. shown in gauge one minute after closing valve, less any pressure which may have been indicated before closing valve.

If the discharge is needed at any other pressure than that

TABLE XL.—Flow of Natural Gas, in Cubic Feet per Day, from Various-Sized Orifices.

Observed Pressure by Mercury Gauge, in Inches.	Observed Pressure by Water Gauge, in Inches.	Observed Pressure by Pressure Gauge, in Lbs. per Square Inch.	Diameter of Orifice or of Well Mouth where Observed.						
			1 Inch.	1½ Inches.	2 Inches.	3 Inches.	4 Inches.	5 Inches.	6 Inches.
...	.1	.0036	12,390	27,880	49,556	111,510	198,220	309,750	446,040
...	.2	.0073	17,560	39,510	70,260	158,040	281,040	439,000	632,160
...	.3	.0109	21,480	48,330	85,940	193,320	343,760	537,000	773,280
...	.5	.0182	27,720	62,370	110,880	249,480	443,520	693,000	997,920
.05	.7	.0254	32,820	73,840	131,260	295,380	525,050	820,400	1,181,520
.07	1.0	.0364	39,210	88,230	156,830	352,890	627,310	980,400	1,411,600
.11	1.5	.0545	48,030	108,070	192,120	432,270	768,480	1,200,800	1,729,100
.15	2.0	.0727	55,340	124,520	221,360	498,060	885,440	1,383,600	1,992,200
.22	3.0	.109	67,910	152,800	271,630	611,190	1,086,510	1,698,000	2,444,800
.29	4.0	.145	78,410	176,420	313,660	705,690	1,254,620	1,960,400	2,822,800
.37	5.0	.182	87,670	197,260	350,670	789,030	1,402,670	2,193,600	3,156,100
.52	7.0	.254	103,500	232,880	414,000	931,500	1,656,000	2,587,600	3,726,000
.74	10.0	.3636	123,000	276,750	492,000	1,107,000	1,968,000	3,075,000	4,428,000
1.02	13.75	.50	146,220	328,990	584,880	1,316,000	2,339,500	3,655,500	5,864,000
1.52	20.62	.75	175,350	394,540	701,400	1,578,150	2,805,600	4,384,000	6,312,600
2.03	27.5	1.00	201,800	454,010	807,200	1,816,050	3,228,500	5,044,600	7,264,200
3.05	41.25	1.5	247,840	557,650	991,370	2,231,000	3,965,000	6,196,000	8,922,000
4.07	55.0	2.0	285,130	641,540	1,140,500	2,566,200	4,562,000	7,128,000	10,265,000
5.08	68.75	2.5	316,500	712,130	1,266,000	2,848,500	5,064,000	7,913,000	11,349,000
6.10	82.50	3.0	344,350	774,780	1,377,400	3,099,100	5,510,000	8,609,000	12,397,000

7.12	96.25	3.5	370,000	832,500	1,480,000	3,330,000	5,920,000	9,250,000	13,320,000
8.13	110.0	4.0	393,000	884,250	1,572,000	3,537,000	6,288,000	9,825,000	14,148,000
8.15	...	4.5	415,270	934,350	1,661,100	3,737,400	6,644,000	10,382,000	14,950,000
10.17	...	5.0	436,200	981,450	1,744,800	3,925,800	6,979,000	10,905,000	15,703,000
11.18	...	5.5	456,200	1,026,500	1,824,800	4,105,900	7,299,000	11,405,000	16,423,000
12.20	...	6.0	473,750	1,065,900	1,895,000	4,264,000	7,580,000	11,844,000	17,055,000
13.21	...	6.5	489,840	1,102,100	1,959,400	4,409,000	7,837,000	12,246,000	17,634,000
14.23	...	7.0	505,920	1,138,300	2,023,700	4,553,300	8,095,000	12,648,000	18,213,000
15.25	...	7.5	522,010	1,174,500	2,088,000	4,698,000	8,353,000	13,050,000	18,792,000
16.26	...	8.0	538,500	1,211,600	2,154,000	4,846,000	8,616,000	13,462,000	19,386,000
18.30	...	9.0	565,970	1,273,200	2,263,000	5,093,000	9,054,000	14,147,000	20,371,000
20.33	...	10.0	589,270	1,325,900	2,357,100	5,303,000	9,428,000	14,372,000	21,214,000
24.39	...	12.0	633,340	1,425,000	2,533,300	5,700,000	10,133,000	15,833,000	22,800,000
28.46	...	14.0	675,000	1,508,800	2,700,000	6,075,000	10,800,000	16,875,000	24,300,000
32.53	...	16.0	713,550	1,605,500	2,854,200	6,422,000	11,415,000	17,839,000	25,688,000
36.60	...	18.0	748,650	1,684,500	2,994,600	6,738,000	11,978,000	18,716,000	26,951,000
40.66	...	20.0	779,350	1,753,500	3,117,400	7,014,000	12,470,000	19,484,000	28,057,000
50.81	...	25.0	845,150	1,901,600	3,381,000	7,606,000	13,522,000	21,129,000	30,425,000
61.00	...	30.0	902,180	2,029,900	3,609,000	8,120,000	14,435,000	22,555,000	32,478,000
71.16	...	35.0	954,820	2,148,300	3,819,000	8,593,000	15,277,000	23,870,000	34,373,000
...	...	40.0	998,680	2,247,000	3,995,000	8,988,000	15,979,000	24,967,000	35,952,000
...	...	45.0	1,036,700	2,332,600	4,147,000	9,330,000	16,587,000	25,918,000	37,321,000
...	...	50.0	1,072,000	2,412,000	4,288,000	9,648,000	17,152,000	26,800,000	38,592,000
...	...	55.0	1,106,880	2,495,000	4,428,000	9,962,000	17,710,000	27,672,000	39,848,000
...	...	60.0	1,137,600	2,559,600	4,550,000	10,238,000	18,101,000	28,440,000	40,953,000

For temperature of flowing gas where observed of 30°, 40°, 50°, 60° Fahr., add 4, 3, 2, 1 per cent. respectively.

To change the result by this table to that for any other specific gravity of gas than 0.6, multiply by $\sqrt{\frac{0.6}{\text{Sp. gr. gas.}}}$

Should 98 per cent. alcohol be used in gauge, multiply the readings by 0.8 to reduce to water value.
Should .75 specific gravity kerosene be used in gauge, multiply the readings by .75 to reduce to water value.

of the atmosphere, the increase of pressure is noted during the minute after the desired pressure has been reached.

There is always a perceptible, and frequently a considerable decrease in the yield of gas from oil-wells when bailing or pumping is suspended, and in the case of bailing wells where measurements of output can only be made on a cessation of bailing, the measured flow is often far below the actual normal yield. In such estimations, therefore, one can always consider the measured results to constitute a minimum.

The normal flow of gas from ordinary bailing and pumping wells is so small that no pressure is recorded on a common water gauge, and the area of orifice must be decreased until a head can be read. In wells lined with screwed casing this end can be best achieved by introducing into the well a tube about 10 feet long, to which is attached a disc flange near the upper end, beneath which a piece of insertion is placed to make a tight joint between the casing collar and the flange. If no pressure is then recorded a smaller tube may be inserted inside the latter.

In the case of wells of large diameter where often riveted casing is used, and there is an escape of gas through faulty joints near the surface when the pressure rises, it is necessary to lower a disc on the tube some distance down the well to avoid the leakages which are sure to take place where the casing is not encircled by earth. A gas-tight joint may be made above the disc by covering it first with cotton waste, and then sand and clay until no escape of gas occurs.

Combustion of Natural Gas.—Where natural gas exists under considerable pressure, and it is led direct to centres of activity, the pressure is automatically reduced from the main to from 3 to 6 inches of water before admission to the distributing mains for general supplies. Where, however, the gas is led direct from gas wells under a pressure of many lbs. per square inch to power houses, it is often burnt direct in the

boiler without the use of any form of burner, or the provision of any special furnace front, the natural force of the gas inducing sufficient draught of air to the burner to readily support combustion. Where the gas pressure does not exceed a few ounces per square inch some form of burner is necessary, whereby the gas and air are intimately commingled and the mixture burns as in an ordinary Bunsen burner. Fig. 114 shows a popular form of American low pressure gas burners which possesses all the main qualities demanded to secure perfect combustion of the gas. The gas is admitted from an annular chamber to the internal portion of the burner through numerous small orifices arranged spirally and at an angle,

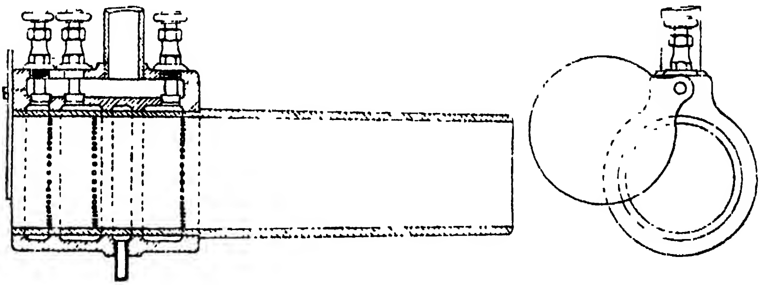

FIG. 114.—GWYNNE GAS BURNER.

so that the gas issues at an angle and is given a swirling motion and becomes intimately commingled with the air induced through the burner. The correct amount of air is secured by adjustment of a door on the burner front, and the gas supply is regulated by the gas cocks. In the burner illustrated there are three rings of holes of different sizes each connected with an independent cock, so that gas with pressures of an ounce to 10 or 12 ounces of water can be economically burnt. The holes on the front circle are $\frac{1}{8}$-inch diameter, for pressures between 4 and 8 ounces of water, the second circle are $\frac{3}{16}$ for pressures below 4 ounces, and the third are $\frac{7}{64}$-inch holes for pressures above 8 ounces. By opening all the cocks full the burner will give its full power with 1 ounce of

pressure and by using a steam jet gas can be drawn into the burner.

Where it is not desirable to place any back pressure on the wells, the gas is often exhausted slightly by a steam injector, which also induces the necessary draught of air to produce combustion.

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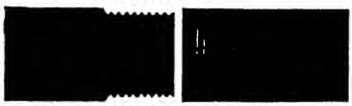
Casing or Lining Tube, with taper screw and socket joint.

Artesian Joint.—Light Boring Tube Inserted Joint.

Heavy Drive Pipe, with extra strong barrel-shaped sockers.



Artesian Joint.—Heavy Boring Tube Flush inside and outside.